Technical Report Documentation Page

1. REPORT No.

2. GOVERNMENT ACCESSION No.

3. RECIPIENT'S CATALOG No.

4. TITLE AND SUBTITLE

Moisture Sensors and Their Place in Highway Plantings

5. REPORT DATE

1988

6. PERFORMING ORGANIZATION

7. AUTHOR(S)

Mong X. Nguyen and David Sollenberger

8. PERFORMING ORGANIZATION REPORT No.

9. PERFORMING ORGANIZATION NAME AND ADDRESS

State of California
Department of Transportation
Division of Construction
Office of Transportation Laboratory

10. WORK UNIT No.

11. CONTRACT OR GRANT No.

13. TYPE OF REPORT & PERIOD COVERED

12. SPONSORING AGENCY NAME AND ADDRESS

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

2. Objectives

1) Develop a laboratory prototype system in which a wide variety of moisture sensors could be tested. They will be rated as to their installation and maintenance requirements plus reliability in regards to their use within a highway landscape.
2) Conduct a field investigation of the various sensors selected from the prototype system, to determine if they can successfully be integrated into an existing highway landscape irrigation system.
3) Determine possible water savings if the moisture sensors prove successful.
4) Develop general guidelines based upon the findings of this report on the use of moisture sensors within a highway landscape irrigation system.

17. KEYWORDS

18. No. OF PAGES:

128

19. DRI WEBSITE LINK

http://www.dot.ca.gov/hq/research/researchreports/1981-1988/88-10.pdf

20. FILE NAME

88-10.pdf

DND
88-10

[redacted]

STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION
OFFICE OF TRANSPORTATION LABORATORY

MOISTURE SENSORS AND THEIR PLACE IN HIGHWAY PLANTINGS

Study Supervised by .... Mas Hatano, P.E.

Principal Investigator .... Bennett John, P.E.

Co-Investigators .... Theodore Bakker, P.E.
Mong X. Nguyen

Report Prepared by .... Mong X. Nguyen
David Sollenberger, P.E.

RAYMOND A. FORSYTH, Chief
Office of Transportation Laboratory

DNP 88-10

NOTICE

The contents of this report reflect the views of the Office of Transportation Laboratory which is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

Neither the State of California nor the United States Government endorse products or manufacturers. Trade or manufacturers' names appear herein only because they are considered essential to the object of this document.

CONVERSION FACTORS

English to Metric System (SI) of Measurement

Quality	English unit	Multiply by	To get metric equivalent
Length	inches (in)or(")	25.40 .02540	millimetres (mm) metres (m)
	feet (ft)or(')	.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in^2) square feet (ft^2) acres	6.432×10^{-4} .09290 .4047	square metres (m^2) square metres (m^2) hectares (ha)
Volume	gallons (gal) cubic feet (ft^3) cubic years (yd^3)	3.785 .02832 .7646	litre (1) cubic metres (m^3) cubic metres (m^3)
Volume/Time (Flow)	cubic feet per second (ft^3/s	28.317	litres per second 1/s)
	gallons per minute (gal/min)	.06309	litres per second (1/s)
Mass	pounds (lb)	.4536	kilograms (kg)
Velocity	miles per hour (mph) feet per second (fps)	.4470 .3048	metres per second (m/s) metres per second (m/s)
Acceleration	feet per second squared (ft/s^2)	.3048	metres per second squared (m/s^2)
	acceleration due to force of gravity (G) (ft/s^2)	9.807	metres per second squared (m/s^2)
Density	(lb/ft^3)	16.02	kilograms per cubic metre (kg/m^3)
Force	pounds (lbs) (1000 lbs) kips	4.448 4448	newtons (N) newtons (N)
Thermal Energy	British termal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds (ft-lb) foot-kips (ft-k)	1.356 1356	joules (J) joules (J)
Bending Moment or Torque	inch-pounds (in-lbs) foot-pounds (ft-lbs)	.1130 1.356	newton-metres (Nm) newton-metres (Nm)
Pressure	pounds per square inch (psi)	6895	pascals (Pa)
	pounds per square foot (psf)	47.88	pascals (Pa)
	atmosphere	98.7	centibar
Stress Intensity	kips per square inch square root inch ($ksi\sqrt{in}$)	1.0988	mega pascals$\sqrt{metre}$ ($MPa\sqrt{m}$)
	pounds per square inch square root inch ($psi\sqrt{in}$)	1.0988	kilo pascals$\sqrt{metre}$ ($KPa\sqrt{m}$)
Plane Angle	degrees (°)	0.0175	radians (rad)
Temperature	degrees fahrenheit (F)	$\frac{+F - 32}{1.8} = +C$	degrees celsius (°C)

DEFINITIONS

Centibar = A unit of pressure equal to 0.01 bar or to 1000 pascals. Symbolized cb

Bar = A unit of pressure equal to 10^5 pascals, or 10^5 newtons per square meter, or 10^6 dynes per square centimeter. It is slightly less than one atmosphere, about 0.98697 standard atmosphere.

Pascal = A unit of pressure equal to the pressure resulting from a force of 1 newton acting uniformly over an area of 1 square meter. Symbolized Pa

Field Capacity = Occurs when the soil retains the maximum amount of water with little or no further loss of water by drainage or loss of gravitational water.

ACKNOWLEDGMENTS

The authors wish to thank the following Caltrans personnel for their contributions during various phases of this project:

Bill Kenny .... District 3, Maintenance
Larry Hammond .... District 4, Maintenance
Drew Letinich .... District 4, Maintenance
Phil Olivares .... Office of Highway Maintenance
Dick Pryor .... Office of Landscape Architecture
Bill Grottkau .... Transportation Laboratory
John Ehsan .... Transportation Laboratory
Pete Zaniewski .... Transportation Laboratory
John Haynes .... Transportation Laboratory
Ed Fong .... Transportation Laboratory
Bruce Coholan .... Transportation Laboratory
Irma Remmen .... Transportation Laboratory
Bill Taylor .... Transportation Laboratory
Lydia Burgin .... Transportation Laboratory

TABLE OF CONTENTS

TABLE OF CONTENTS (con't.)

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

In recent years, faced with rising water costs and increased water shortages, the California Department of Transportation (Caltrans) has undertaken several research projects directed at reducing the present consumption of potable water used in the irrigation of highway landscapes. Included were studies on drip irrigation systems, the use of reclaimed wastewater, and different techniques associated with programming the automatic irrigation controllers.

In 1983 the Caltrans Office of Highway Maintenance requested the Office of Transportation Laboratory (TransLab) to conduct a research project to determine the feasibility of using moisture sensing devices to regulate automated irrigation systems. In April 1984, the Federally funded research project (R83HM23) entitled "Moisture Sensors and Their Place in Highway Plantings" was approved. In January 1987, a supplemental State financed project, with the same title, (56-627151) was approved to provide additional funding for extended testing and analysis of the sensing devices.

This report has been prepared to fulfill the requirements of both the Federal and State funded projects.

2. OBJECTIVES

1) Develop a laboratory prototype system in which a wide variety of moisture sensors could be tested. They will be rated as to their installation and maintenance requirements plus reliability in regards to their use within a highway landscape.

2) Conduct a field investigation of the various sensors selected from the prototype system, to determine if they can successfully be integrated into an existing highway landscape irrigation system.

3) Determine possible water savings if the moisture sensors prove successful.

4) Develop general guidelines based upon the findings of this report on the use of moisture sensors within a highway landscape irrigation system.

3. CONCLUSIONS AND BENEFITS

1) Of the ten moisture sensors investigated in the prototype system, four (Watermatic, Watermark, Hydrovisor, and Hydrodyne) achieved satisfactory results in the installation and maintenance requirements and were considered reliable. A fifth, Hydromaster, although not thoroughly tested, appeared to have the attributes to be considered in either further investigations involving moisture sensors or actual field installations.

2) Three sensors, Watermark, Hydrovisor and Hydrodyne were investigated at two field test sites, Sacramento and Oakland. The Watermatic sensor was not included in the field investigation due to the anticipated unavailability of equipment.

3) The three sensors tested provided acceptable installation and reliability results in their usage of overriding individual irrigation valves. No special equipment was needed for the installation of the units and all functioned properly during the test period. No maintenance was required once calibration of the units was completed.

4) All sensors showed water savings over allotted irrigation times varying from 10 to 72 percent. However, this savings was dependent upon the scheduled irrigation times. Some of the savings encountered at the Sacramento field site did not accurately reflect the actual water savings due to adjustments made on the allotted times to certain stations involved in the investigation.

5) At the Sacramento field site it is estimated that if installed on a permanent basis a water savings of 10 to 20 percent could be obtainable. At the Oakland site it is estimated that 10 to 50 percent reduction could be obtained.

6) Although the use of certain moisture sensors within a highway landscape environment has been proven reliable with low maintenance requirements, this

study only investigated the use of one moisture sensor per irrigation valve. Due to the cost requirements, it is anticipated that in most instances one sensor per valve would be too cost prohibitive.

Benefits:

The benefit derived from this research project is the reduced amount of water needed for landscape irrigation. This translates into a reduced cost for water used by Caltrans.

4. RECOMMENDATIONS

1) That the Watermark, Hydrovisor, or Hydrodyne moisture sensor be retrofitted into existing highway landscape irrigation systems and incorporated into the design of new systems to reduce present water consumption rates an estimated 10 to 50 percent.

2) That the moisture sensors be installed in conjunction with any 24-volt electrically operated irrigation valve with any type of irrigation system; overhead, bubbler, drip, etc. Limitations include locations where the valve and sensor are separated by a roadway or sidewalk or where sensors might create excessive or insufficient water pressure when booster pumps are utilized in the irrigation system.

3) That moisture sensors be used with any type of vegetation; trees, shrubs or groundcover. Care must be exercised when determining the location for the sensor. A location that is representative of the entire watering area affected is required.

4) That the installation procedures follow those outlined in the "Guidelines" chapter of this report.

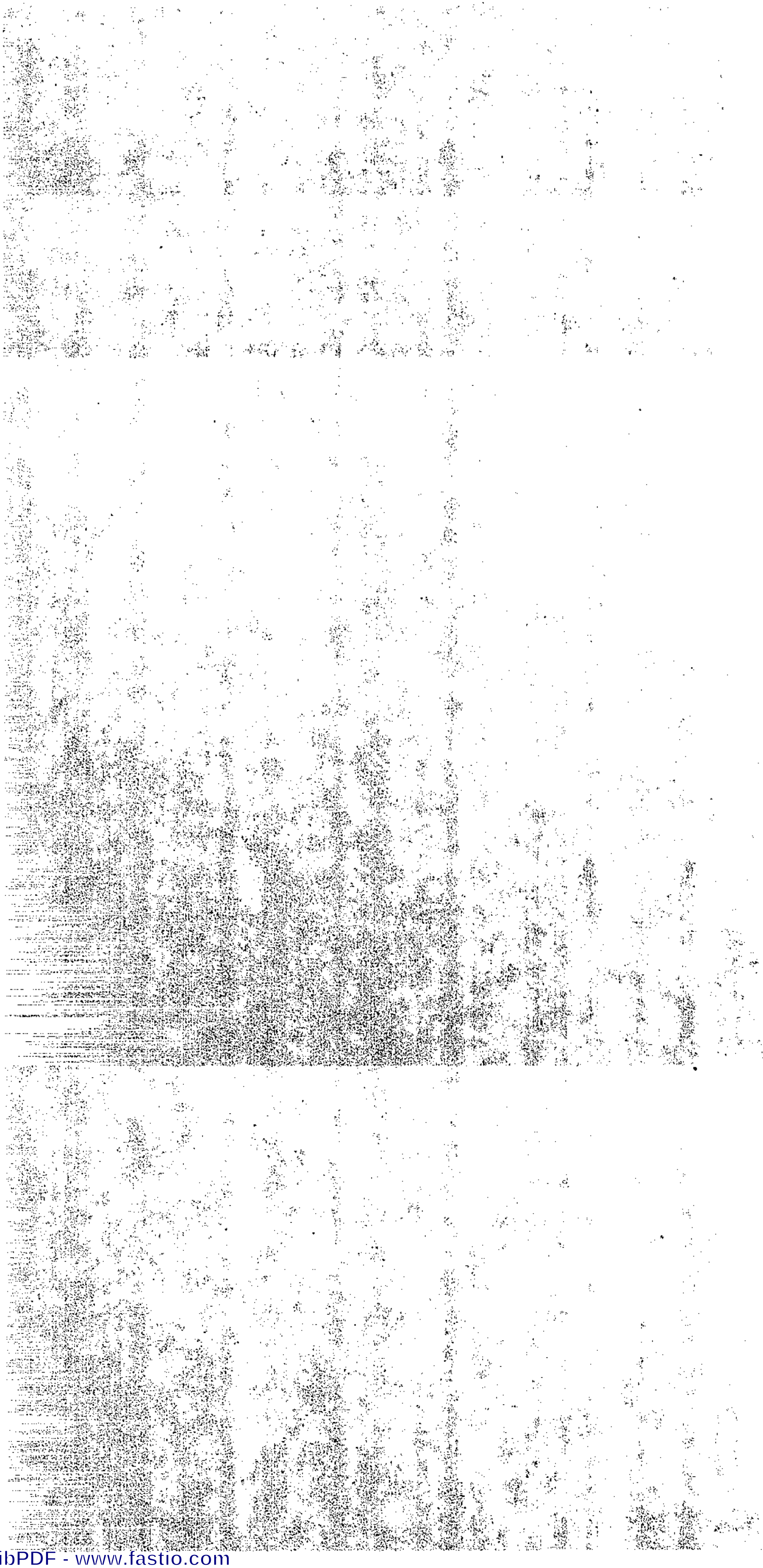
5) That, at this time, the existing controller programmed irrigation schedules remain unchanged when using moisture sensors.

6) That training classes be developed that will instruct landscape maintenance and design personnel on all aspects of the use of moisture sensors.

7) That an additional study be conducted to determine the feasibility of connecting one sensor per controller. Included in this investigation should be the interconnecting capabilities of the previously tested sensors with existing irrigation equipment, the placement of the sensor, and proper water schedules for the irrigation controllers. Included in this study should be the Watermatic and Hydromaster moisture sensors.

5. IMPLEMENTATION

Copies of this final report will be distributed to Caltrans District and Headquarters Offices and the Federal Highway Administration for implementation. Information derived from this research study will be made available to landscape designers and landscape maintenance personnel to improve the efficiency of both new and existing landscape irrigation systems through the use of moisture sensors. The Offices of Landscape Architecture and Highway Maintenance will be responsible for implementing the recommendations and findings of this study. TransLab personnel will assist with technical problems as requested, including statewide training sessions for Caltrans maintenance and design personnel. The results of this study may also serve as the basis for additional studies concerning the use of moisture sensors in highway landscape systems.



6. BACKGROUND

In order to develop an effective and efficient irrigation management program the quantity of moisture present in the soil matrix, under consideration, must be easily extractable. The moisture content can be used as a guide for the frequency and duration of irrigation cycles depending upon the vegetative requirements. Too much water can deprive the root structure of an adequate oxygen supply which can lead to death, not to mention being a wasteful water practice. Too little water induces undue stress on the vegetation slowing growth and reproduction, and if severe enough, can cause irreversible damage or death.

Historically, the moisture content was acquired by obtaining a soil sample then weighing, drying, and reweighing it. Although labor intensive and time consuming it provided a basis for irrigation scheduling. As irrigation management became more advanced, faster and easier methods for determining the in situ moisture content were needed.

The development of soil moisture sensing equipment began as early as 1897 but did not gain much momentum until the late 1930's. The information obtained was almost exclusively used by the farming industry as an aid in maximizing crop production. Not until the drought of the mid 1970's was the usefulness of the moisture sensing devices realized by the landscaping industry as well.

6.1 Types of Moisture Sensors

A variety of moisture sensing devices currently exist which measures the water content of soils in different and unique ways. These include electrical resistance sensors, tensiometers, thermocouple psychrometers (1), heat dissipation sensors (1), specially designed nuclear devices (2), infrared sensors (3), and ultra-sensitive microphones which can detect high frequency sound emitted by vegetation under stress (4). However, only the electrical resistance and tensiometer moisture sensors were investigated in this report. The other types were considered too sophisticated and impractical for use in a highway landscape environment at this time. More information on the sensors used in this investigation are in Appendix A.

Moisture sensor measurements can be classified into two basic categories, passive or active. Passive measurement moisture sensors can only be used to obtain the soil moisture readings, which in turn can be used to develop an irrigation schedule. Active measurement sensors have the capability of overriding automatic irrigation equipment, initiating or terminating watering cycles when a predetermined moisture level is detected. Depending upon the specific sensor model, the soil moisture readings may also be obtainable with active measurement sensors.

6.1.1 Electrical Resistance

Dating back to 1897, the first electrical resistance moisture sensor was developed (5). It consisted of two electrodes buried within the soil structure. The resistance to the passage of a current through the soil was measured and the amount of water determined.

Since that time, many attempts of perfecting a sensor based on this concept have been developed. In 1939 Bouyoucos and Mick (6) introduced a sensor consisting of two electrodes encased in a porous gypsum material. The gypsum blocks, although providing semi-accurate results, were affected by changes in the salinity of the soil and decomposed rapidly under moist soil conditions. Other materials including fiberglass (7) and nylon (8) were investigated along with using shielded and concentric electrodes (9).

With the advances in electronics and computerization in the last decade, and with the market expanding to include the landscaping industry, a variety of new sensors have been developed offering many advantages over the earlier versions. However, the principle remains unchanged.

6.1.2 Tensiometers

Tensiometers are air-tight systems consisting of a water-filled tube, usually plastic, with a porous ceramic tip at one end and a pressure gauge or switching mechanism at the other. When installed the system is originally at atmospheric pressure. In dry soils the water is drawn out of the tube creating a vacuum; the drier the soil, the greater the vacuum. This vacuum can either be registered on a pressure gauge or converted into voltage through a pressure transducer and used to override irrigation equipment. As irrigation replenishes the water supply within the soil, water is drawn back into the system, reducing the vacuum.

The major disadvantages of tensiometers, as reported by Slater and Bryant (10) and Storm and Younos (1), are high maintenance requirements, ineffectiveness in drier soils, and inability to operate under freezing weather conditions.

6.2 Previous Caltrans Installations

A total of six different moisture sensors have been investigated in previous attempts by Caltrans landscape architects and maintenance personnel throughout the state. These include the Irrometer and Hydrovisor in Pasadena, Aquascan in Oakland, Watermaster in Templeton (San Luis Obispo County), and Moisture Miser and Hydrodyne in San Diego.

6.2.1 Irrometer (11)

Installed in a newly developed landscaped area, between six and eight Irrometer moisture sensors were installed on Route 7 in Pasadena and connected to an automatic irrigation controller. Operation and monitoring, conducted by District 7 (Los Angeles) maintenance personnel, began in August 1980 and continued until August 1981.

Landscape maintenance personnel reported that each time the units were checked (approximately once a week) they were dry and needed to be refilled with water. Also, during the winter months it was noted that the units allowed irrigation even after substantial rainfall had occurred. Maintenance effort needed to keep them operational became so excessive that the units were disconnected in August 1981.

The conclusions of this one year monitoring program include: (1) the units did not justify the manufacturer's claims of 50% to 60% water savings, (2) the units did not react quickly enough during the rainy season, (3) the units were a maintenance burden, and (4) a better design is needed; the Irrometer is designed to turn off the system and to not allow for irrigation when the vacuum is lost (i.e. no water in the tube).

6.2.2 Hydrovisor (11)

In conjunction with the Irrometer installations, eight Hydrovisor solid state tensiometers were installed in an adjacent area along Route 7 and connected to an irrigation controller. Monitoring was conducted August 1980 through August 1981. In April 1981, all of the units were manually checked by removing them from the ground and immersing them in water. Six of the eight were found to be nonfunctional.

Results from the Hydrovisor investigation include: (1) the units did not attain a water savings of 50% to 60% as stated by the manufacturer, (2) the units did not react quickly enough during the rainy season, (3) since there were no gauges on the sensing units each had to be unearthed and immersed in water to check if they were still functioning, and (4) 75 percent of the units became defective within a one year period.

6.2.3 Aquascan (12)

Installed in 1981 in an existing landscaped area along I-980 in Oakland, the Aquascan microprocessor and moisture sensor probes were monitored throughout the 1982 watering season by District 4 (San Francisco) landscape maintenance personnel. Results of the first year's evaluation indicate that there was almost a 50 percent water savings over water usage in 1979. No operational problems were reported. The sensor probes only had a useful life of one year at which time they had to be replaced (approximately two dollars per set). Maintenance personnel considered the replacement of the probes no problem at the time.

In subsequent conversations with landscape personnel it was discovered that technical problems with the Aquascan controller developed in 1983. In attempting to contact the manufacturer they discovered Aquascan had gone out of business. At that time the unit was removed and replaced with a standard Caltrans irrigation controller.

6.2.4 Watermaster (13)

In the spring of 1984, two Watermaster water-filled tensiometers were installed at the south-bound San Anselmo off-ramp of Highway 101 in Templeton, and two more were installed at the northbound Camp Roberts Safety Roadside Rest Area (SRRA) by District 5 (Santa Barbara) maintenance personnel. The units were not connected to irrigation controllers, but the information obtained was to be used to develop irrigation schedules for the area. Monitoring occurred throughout the summer of 1984. The various reasons leading to the discontinuance of these units are discussed below.

Maintenance personnel reported that the two sensors located at the San Anselmo off-ramp were requiring the addition of water approximately every five days. The area in which the sensors were located was noted as containing considerable quantities of fractured rock and did not appear to be an ideal locations for the moisture sensors.

The sensors installed at the SRRA were located in the middle of a grassed area which obtained regularly scheduled irrigation. The maintenance personnel contacted stated that the sensors were always reading "10", indicating a saturated condition. This would lead one to believe that either excessive irrigation or improper maintenance of the equipment was occurring; neither could be confirmed.

6.2.5 Moisture Miser (14)

A Moisture Miser sensing unit was installed at the District 11 (San Diego) office in the spring of 1984. At the time of the installation landscape work was being conducted in the area and the sensor was not connected. However, it was anticipated to be working prior to the 1985 watering season.

Landscape work continued throughout 1985 and in early 1986 it was discovered that the company that manufactured and marketed the Moisture Miser had gone out of business and the study was dropped.

6.2.6 Hydrodyne (15)

A Hydrodyne moisture sensor was installed by District 11 (San Diego) personnel and connected into a highway irrigation system at the base of the Coronado bridge located in San Diego during the fall of 1985. No records were kept of the quantity of water used or saved while the unit was in operation. However, conversations with maintenance personnel in charge of the area indicated that the unit was functioning properly with no problems; the vegetation was receiving adequate water and no runoff was being noticed.

7. PROTOTYPE SYSTEM

Due to the past unsuccessful attempts of using moisture sensors within Caltrans, a prototype system was developed at TransLab to determine which type, if any, of the currently available moisture sensing units could be successfully used in conjunction with highway landscape irrigation systems. Although the goal of using moisture sensors is to be able to reduce the present consumption of irrigation water within the state, the prototype system portion of the investigation was not concerned with the water savings potential. The main objective was to obtain the necessary information pertaining to the installation and operational characteristics of the various sensors before field testing of the units could be conducted.

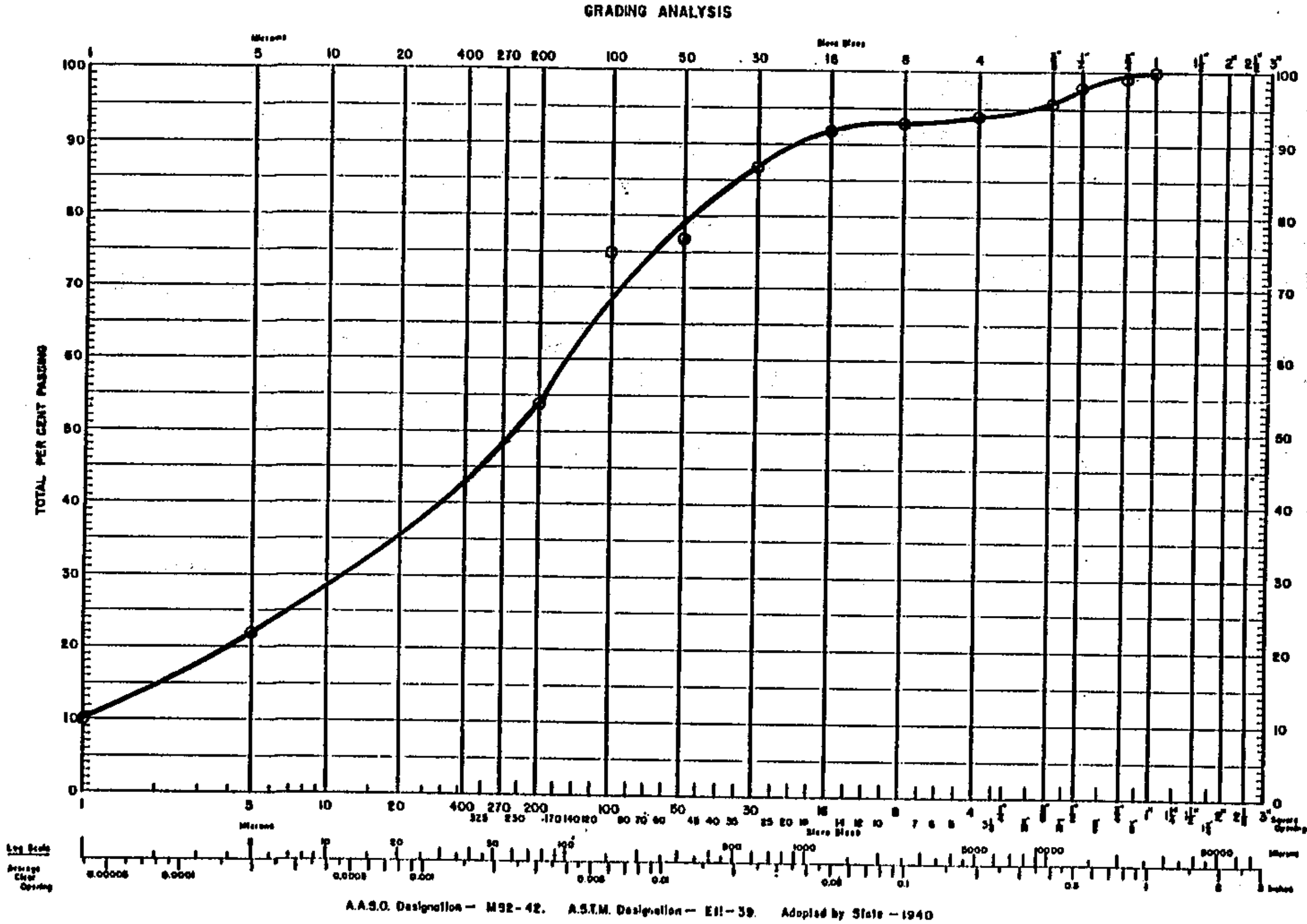
To achieve this objective, the prototype system consisted of three phases: installation procedures, operational characteristics and reliability, and the development of a rating system. From the data collected during the installation and operation portions of the laboratory evaluation, each sensor was appropriately ranked. Those sensors meeting the minimum requirements were then selected for the field evaluation portion of this project.

7.1 Site Description

The prototype system developed at TransLab encompassed an area approximately 30 by 45 feet. The soil gradation results (Figure 7.1), indicated that the soil was a sandy loam. The soil did not drain well due to cementing of the soil particles. A soil nutrient test indicated that no additional fertilizer or soil amendments were required.

An automatic irrigation system was installed, including a 15 psi. pressure regulator, a 150 mm mesh in-line filter, ten irrigation control valves, a Rainbird 12-independent station controller, and the Aquascan microprocessor controller (Figure 7.2). The Rainbird controller was used to operate seven irrigation valves while the Aquascan controller operated three. A single

SOIL GRADING ANALYSIS



LABORATORY PROTOTYPE SYSTEM

FIGURE 7.1

Laboratory Prototype System

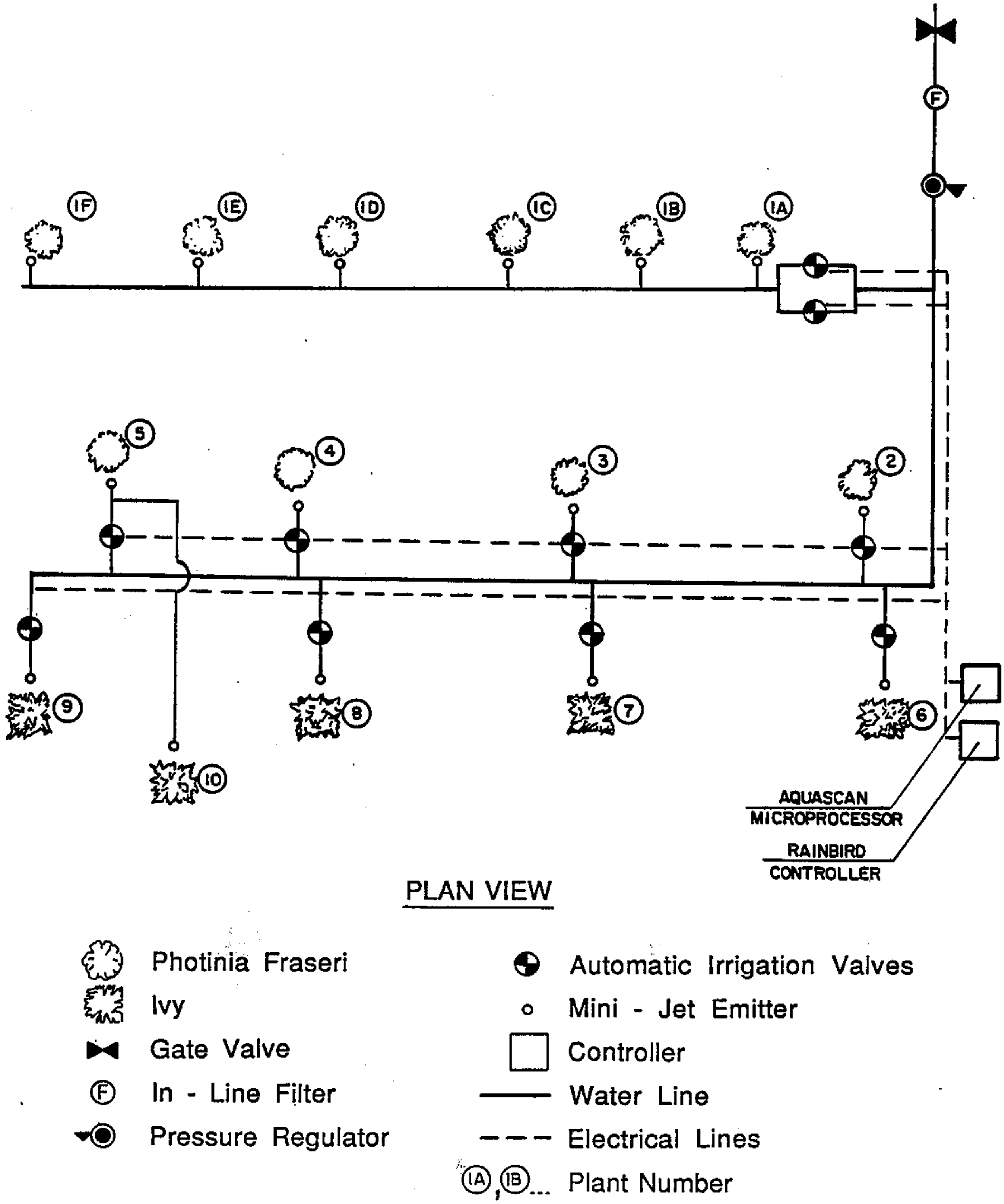


FIGURE 7.2

mini-jet spray emitter (0.254 gallons per minute) was used at each planting and arranged so that over spray of the plants would not occur. During the course of the investigation several changes were made in regards to the testing program which dictated slight modifications to the irrigation system.

The vegetation selected for use in this portion of the research work consisted of English Ivy (Hedera helix) and Photinia fraseri (commonly referred to only as Photinia). The difference in the active depth of the root zones, 2 to 3 inches and 10 to 15 inches, respectively, and the fact that both species are widely used in Caltrans' landscapes were the basic criteria for their selection.

Ten 5-gallon Photinias were transplanted in March 1985, and positioned in two rows, labeled 1-A through 1-F, and 2 through 5, along with five 3 by 3-foot plots of ivy labeled 6 through 10 (Figure 7.2). Plantings 5 and 10 were used as the control sections. These numbers will be referred to throughout the remainder of this report.

A watering schedule of ten minutes per cycle, three cycles per day and seven days per week was established at the onset of the project and remained throughout the entire experiment. This schedule, although, unrealistic for standard watering practices, allowed numerous start times in which the responses of the various sensors could be examined.

7.2 Moisture Sensor Installations and Operations

Ten different moisture sensors were incorporated into the prototype system: 1) Soilmoisture Block, 2) Irrometer, 3) Watermaster, 4) Aquascan, 5) Watermatic, 6) Watermark, 7) Hydrovisor, 8) Moisture Miser, 9) Hydrodyne, and 10) Hydromaster. Originally, only the first seven sensors were to be investigated, but sensors # 8, 9, and 10, developed and marketed since the onset of the project, warranted inclusion into the prototype system. A description of each sensor is given in Appendix A.

After allowing the vegetation to become established, the seven original sensors were installed during June 1985. The other three, Moisture Miser, Hydrodyne, and Hydromaster were integrated into the system in December 1985, January 1986, and September 1986, respectively. The quantities and placement of the various sensors that were utilized are shown in Table 7.1. Table 7.2 lists the key installation constituents and summarizes the problems encountered with the various sensors while establishing the prototype system.

Monitoring of the sensors began on July 15, 1985 and continued until July 9, 1986. Observations were conducted daily until October and triweekly thereafter. The data collected is presented in Appendix B.

During the course of the investigation, several of the sensors became damaged and nonoperational. It was also discovered that two of the manufacturers had gone out of business. Table 7.3 summarizes these results and Table 7.4 summarizes the attributes of the individual sensors.

7.2.1 Soil Moisture Blocks

As previously discussed, moisture sensor measurements are divided into two categories, active or passive. Since the Soilmoisture Blocks are passive measurement sensors only, 38 sensors were installed to determine if the other active measurement moisture sensors did in fact accurately respond at their predetermined moisture settings. Three sensors were located at each of the Photinia plantings at depths of 8, 12, and 20 inches. Two sensors were placed at each of the ivy plots, except at planting 10 where none were installed. The sensors were placed at a three inch depth.

No problems were encountered with the installation of the units. Care had to be exercised when placing the sensors that the wire connections were not damaged. A hand held meter was required to obtain the moisture readings.

The data obtained during the first several months of the experiment showed that no correlation between the Soilmoisture block sensor readings and the

Table 7.1

MOISTURE SENSOR INSTALLATION QUANTITIES

	Planting 1A-1F	2	3	4	5	6	7	8	9	10	1-D	1-E	Total
Soilmoisture Blocks	18(1)	3	3	3	3	2	2	2	2	0	-	-	38
Irrometer	0	1	2	1	0	0	0	0	0	0	-	-	4
Watermaster	0	0	0	0	0	2	1	1	1	0	-	-	5
Aquascan	2	0	0	0	0	0	0	0	1	0	-	-	3
Watermatic	0	1	0	0	0	1	0	0	0	0	-	-	2
Hydrovisor	0	0	1	0	0	0	1	0	0	0	-	-	2
Watermark	0	0	0	3(2)	1	0	0	2	0	0	-	-	6
Moisture Miser	-	0	0	0	0	0	0	0	0	0	1(3)	-	1
Hydrodyne	-	0	0	0	0	0	0	0	0	0	-	1(3)	2
Hydromaster	-	0	0	0	0	0	0	0	0	0	1(4)	-	1

(1) Three sensors per planting.
(2) A third sensor was installed 11/1/85.
(3) Installed after Aquascan was dropped from study.
(4) Installed after Moisture Miser was dropped from study.

Table 7.2

INSTALLATION CONSTITUENTS AND PROBLEMS

	Water Tight / Vandal Compartment Required	Special Equipment	Initial Adjustment Problems	Adequate Instruction
Soilmoisture Blocks	No	Yes[2]	N/A	Yes
Irrometer	Yes	Yes[3]	No	Yes
Watermaster	Yes	No	No	Yes
Aquascan	No	No	Yes	No
Watermatic	No	Yes[4]	N/A	Yes
Hydrovisor	Yes	No	Yes	Yes
Watermark	Yes[1]	Yes[2]	No	Yes
Moisture Miser	Yes[1]	Yes[3,5]	Yes	No
Hydrodyne	Yes[1]	Yes[2]	No	Yes
Hydromaster	Yes[1]	No	N/A	Yes

(1) Can use existing valve box for equipment storage.
(2) Meter required to obtain readings.
(3) Hand-held pump required.
(4) Special bending compound required.
(5) Co-axial cable required.

Table 7.3

QUANTITY OF INSTALLED AND DAMAGED UNITS

	Units Installed	Units Damaged in 1985	Units Damaged in 1986	Units Functional at end of study	% Funtional at end of study
Soilmoisture Blocks	38	10	9	19	50
Irrometer	4	0	1	3	75
Watermaster	5	5	0	0	0
Aquascan (1)	3	3	0	0	0
Watermatic	2	0	0	2	100
Hydrovisor	2	0	0	2	100
Watermark (4)	6	1	0	5	83
Moisture Miser (2)	1	0	1	0	0
Hydrodyne (3)	1	-	0	1	100
Hydromaster	1	-	0	1	100

(1) Went out of business prior to the prototype study.
(2) Installed December 1985.
(3) Installed January 1986.
(4) Installed September 1986.

Table 7.4

OPERATIONAL CHARACTERISTICS AND ATTRIBUTES OF SENSORS

	Months of Operation	Maintenance Required	Type of Sensor (1)	Measurement Type (2)	Auxiliary Meter Required	Adjustable Setting	Easily Adjustable	Override Switch	Location of Switch (3)	Reliable (See Table 7.5)
Soilmoisture Blocks	12	No	R	P	Yes	No	N/A	N/A	N/A	No
Irrometer	12	Yes	T	B	No	Yes	Yes	Yes	S	No
Watermaster	3	Yes	T	B	No	Yes	Yes	Yes	S	No
Aquascan	0	N/A	R	A	N/A	Yes	No	Yes	C	No
Watermatic	12	No	R	A	N/A	No	N/A	No	N/A	Yes
Hydrovisor	12	No	T	A	N/A	No	N/A	Yes	S	Yes
Watermark	12	No	R	B	Yes	Yes[4]	Yes	No	N/A	Yes
Moisture Miser	0	N/A	R	A	N/A	Yes	No	Yes	V	No
Hydrodyne	9	No	R	B	Yes	Yes	Yes	Yes	V	Yes
Hydromaster	2	No	R	A	N/A	No	N/A	No	N/A	(5)

(1) R = Electrical Resistance T = Tensiometer
(2) P = Passive A = Active B = Both
(3) V = Valve Box S = Sensor C = Irrigation Controller
(4) 3 preset setting available on electronic module.
(5) Not monitored long enough to determine reliability.

moisture readings obtained from the other sensors could be made. The major factor was determined to be the installation procedure of the various sensors. If the soil removed during the sensor installation was not properly recompacted a difference in the permeability of the soil would be expected and different moisture readings would be anticipated. At that time it was decided that in lieu of checking the accuracy of the active sensors with the Soilmoisture Blocks the reliability of the sensors would be checked through visual observations of the soil moisture content and frequency of irrigation.

Of the 38 Soilmoisture Blocks installed in 1985, 19 were no longer functional at the end of the study; ten were damaged in 1985, with the other nine failing in 1986. Inadequate connections between the wire leads and the probes and excessive deterioration of the gypsum used to encase the probes were the suspected reasons for the high rate of damage.

7.2.2 Irrometer

A total of four Irrometers were installed at three of the Photinia plantings; one each at plantings 2 and 4, and two at planting 3. The sensor tips for planting 2 and 4 were placed at a depth of 11 inches. The sensor tips at planting No. 3 were installed at depths of 11 and 14 inches.

Although capable of automatically overriding irrigation valves, the water-filled Irrometers were not connected due to the previously described maintenance problems (Section 6.2.1). During the first part of the testing program, it was intended to verify whether an unreasonable amount of maintenance was required. If maintenance presented no particular problem, the sensing units would then be connected to the irrigation valves.

Installation of Irrometers required the use of an underground, enclosed box for protection from inadvertent or vandal damage. In addition, a special hand-held pump, used to extract the air from the system, was required when filling or refilling the Irrometer with water.

During 1985, all four of the sensors required the addition of water weekly. Due to the excessive amount of maintenance required, the Irrometers were not connected to the automatic irrigation equipment, as discussed.

At the end of the study period, only one of the units was nonfunctional. The damage was limited to the breakage of the rubber seal on the filler cap.

7.2.3 Watermaster

Five Watermaster moisture sensors were installed; one each at plantings 7, 8, and 9, with two at planting 6. All were installed at a 3 inch depth, except the second sensor at planting 6 which was placed at a 5 inch depth. None of the Watermaster sensors were connected to irrigation equipment at this time due to the suspected maintenance problems.

As with the Irrometer sensors, the Watermaster field installations required the use of an enclosed box to protect the units from damage.

The Watermaster tensiometers also required an excessive amount of maintenance. During July 1985, water was added to the units every two to three days. In addition, all five of the vacuum gauge assemblies became inoperable during the first two months of operation. Water vapor was noted inside several of the vacuum gage mechanisms prior to failure. It was decided to discontinue the testing of the Watermaster sensors in August 1985.

7.2.4 Aquascan

Plantings 1-A through 1-F were to be used in a two-part study with the Aquascan microprocessor controller. With the use of two sets of probes; one set placed approximately 40 feet apart, the other set, 4 feet apart, it was intended to determine which distance provided a more accurate measure of the irrigation requirements for the area.

One set of probes was placed at either end of row 1, at a depth of 10 inches, with the second set installed on either side of planting 1-D, again at a depth of 10 inches. Each sensor regulated a separate valve used to irrigate all six shrubs. During the first half of the 1985 irrigation season, the probes set 40 feet apart were to regulate the first valve and if an insufficient moisture level was detected, to initiate irrigation. The second set of probes would then be used as a check; to see if the soil moisture content had reached a satisfactory level. During the second half of the irrigation season the roles of the two sets of probes would be reversed.

At planting 9, one set of Aquascan probes was installed at a depth of 3 inches, 4 feet apart.

Problems with the initial adjustment of the moisture levels were encountered with all three sets of probes. Although there was a fully adjustable moisture range on each set of probes, the valves activated by the respective probes would either remain on or off continuously for a two to three week period until the probes were readjusted. No happy medium was ever found. The instructions that accompanied the unit were unclear and required additional information in both the installation and operation procedures. Having learned that the Aquascan manufacturer had gone out of business, it was decided to discontinue the testing of the Aquascan moisture sensor.

7.2.5 Watermatic

A preset, nonadjustable, 15 kPa (1kPa = 1cb) Watermatic moisture sensor was installed at plantings 2 and 6 at a depth of 9 and 3 inches, respectively and connected to the irrigation valves. A special bedding compound, recommended by the manufacturer to ensure a complete bond between the sensor and the soil, was also used during the installation procedure.

No operational or maintenance related problems were encountered with either of the Watermatic sensors throughout the study period. The accuracy of the switching point was not determined due to the lack of correlation between the various sensors.

7.2.6 Hydrovisor

A 20-30 cb Hydrovisor moisture sensor was installed at a depth of 4 and 10 inches at plantings 7 and 3 respectively on July 15, 1985. On August 12, 1985, the sensor at planting 3 was relocated to a depth of 7 inches after having allowed excessive irrigation to occur. Before replacing the sensor the unit was checked and found to be functional. Since the Hydrovisors are nonadjustable the depth had to be varied to allow for accurate watering requirements. No problems were encountered with the sensor at planting 7. Both were still functional at the end of the investigation during July 1986.

The Hydrovisor units were required to be installed with the override switch, located on the end of the unit, enclosed in a valve box.

7.2.7 Watermark

At planting 4, two Watermark moisture sensors were installed at depths of 10 and 20 inches on July 15, 1985. At the time of installation, the electronic module, used to override the irrigation valve had not been received from the manufacturer. The module was received in August 1985, and connected to the 10 inch deep sensor at the 35 cb preset level. The other sensor remained at the 20 inch depth and was used to monitor the movement of water at the deeper level. This unit became inoperative due to a break in one of the wire leads in September 1985. A third sensor was installed in November 1985 at 14 inches.

At planting 8, two Watermark sensors were installed at depths of 3 and 8 inches. In August 1985, the electronic module was connected to the 3-inch-deep sensor, also at the 35 cb level. The deeper sensor was again used to monitor the movement of water.

A single Watermark sensor was installed at planting 5, at a depth of 10 inches, to monitor the water movement in the control section.

Besides the one sensor at planting 4, no other installation or operational problems were encountered the remainder of the study period.

7.2.8 Moisture Miser

Due to problems with the Aquascan microprocessor unit, previously discussed in Section 7.2.4, the Moisture Miser moisture sensor was installed at planting 1-D in December 1985 at a depth of 8 inches. A slight modification to the irrigation system was made at this time.

The Moisture Miser required the use of coaxial cable to connect the sensor to the control unit. No other special equipment was needed.

Several unsuccessful attempts were made to adjust the moisture level on the Moisture Miser control unit. The manufacturer was contacted by telephone and the additional information that was received also provided unsatisfactory results. Attempting to contact the manufacturer a second time proved unsuccessful. It was learned that they had gone out of business. The Moisture Miser moisture sensor was then dropped from the prototype system.

7.2.9 Hydrodyne

A Hydrodyne moisture sensing unit was installed at planting 1-E in January 1986, at a depth of eight inches. No problems were encountered. The problems with the Aquascan unit (Section 7.2.4) allowed for the inclusion of this sensor.

Due to the time of the year in which the sensor was installed, the adjustable Hydrodyne unit was set at a higher than normal setting. The upper and lower levels were periodically adjusted both up and down to determine the accuracy of the switching mechanism.

From the data in Appendix B it can be seen that on several occasions the measured moisture readings were higher than the upper level setting. This occurred due to rain. Throughout the prototype study the switching point was within the upper and lower settings.

7.2.10 Hydromaster

Manufacturer related problems associated with the Moisture Miser sensing unit (discussed in Section 7.2.8) led to the replacement at planting 1-D with the Hydromaster nonadjustable moisture sensor, in September 1986. The unit was installed at a depth of eight inches. Although the testing of the other moisture sensors was concluded in July 1986, the Hydromaster appeared to have sufficient attributes to warrant inclusion into the prototype system at this time.

No problems were encountered or special equipment required while installing this unit. Since it was received and installed in September 1986, it did not allow for a thorough investigation of this unit prior to completion of the project. However, during the two months that the unit was examined at the laboratory prototype system, no operational or maintenance problems were encountered.

7.3 Rating System

The rating system developed at the onset of the investigation included the more important attributes of the sensors, in regards to highway landscape applications, and the performance of each sensor during the prototype study. Listed below are the seven headings that were selected and the number of points assigned to each; the greater the points, the more important the topic. A score of 50 was established as the minimum requirement for inclusion into the field investigation portion of this project.

1) Reliability. Was the sensor reliable in regards to functional performance as determined in the prototype system? (More than 80 percent functional at end of study.)	Yes = 30 No = 0

2) Maintenance requirements. Was little or no maintenance required during the prototype investigation? Yes = 20 No = 0

3) Override switch. Did the sensor have an override switch so that irrigation could be performed even though sufficient moisture is detected? Yes = 20 No = 0

4) Adjustable. Could the unit be easily adjusted to different moisture level settings? Yes = 10 No = 0

5) Manufacturer/dealer available. Was the manufacturer or a dealer available? Yes = 10 No = 0

6) Temperature affected. Were the units able to withstand temperature extremes (hot or cold) without damage? Yes = 5 No = 0

7) Special equipment. Was any special equipment needed to effectively operate and maintain the units? Yes = 0 No = 5

Although the prototype system was operated until July 1986, the rating of the various sensors was conducted in May of that year due to the time constraints of the second portion of the project. At that time the Hydromaster had not yet been received and, therefore, was not included in the rating system.

The rating of the sensors tested in the prototype investigation is shown in Table 7.5. Four sensors obtained a minimum of 50 points, Watermatic, Hydrovisor, Watermark, and Hydrodyne and were selected for the proposed field investigation portion of the study.

Table 7.5

RATING SYSTEM FOR MOISTURE SENSORS

	Reliable	Low Maintenance	Override Switch	Adjustable	Manufacturer Availability	Temperature Effected	Special Eqipment to operate	Total
Soilmoisture Blocks	0	0	0	0	10	5	0	15
Irrometer	0	0	20	10	10	0	0	40
Watermaster	0	0	20	10	10	0	5	45
Aquascan	0	0	20	0	0	5	5	30
Watermatic	30	20	0	0	0	5	5	60
Hydrovisor	30	20	20	0	10	5	5	90
Watermark	30	20	0	10	10	5	0	75
Moisture Miser	0	0	20	0	0	5	5	30
Hydrodyne	30	20	20	10	10	5	0	95
Hydromaster	(1)	20	0	0	10	5	5	(1)

(1) Not rated due to late of inclusion in project.

8. FIELD EVALUATIONS

A field investigation of the selected moisture sensors previously tested allowed for the acquisition of data that was required prior to the establishment of an implementation program. The major objectives in this portion of the research project were to (A) determine the proper installation procedures within a highway landscape irrigation system and (B) determine and correct any unforeseen problems that might occur in the operation and maintenance of the sensors, (C) evaluate the performance of the sensors within the highway landscape environment and (D) determine the amount of water savings that the use of moisture sensors may generate.

In determining locations for the field study sites, the following criteria were considered:

(1) A minimum of two sites should be used; one in a hot, dry climate, indicative of the central valley, and one in a mild climate, typical of the San Francisco Bay area.

(2) The vegetation should consist mainly of a ground cover, specifically ice plant (Carpobrotus edulis) due to its wide usage within Caltrans.

(3) Southern or western exposed slopes would be preferred, however, a top slope which receives significant sunlight exposure would be acceptable.

(5) Irrigation lines should be located at the top of the slope.

(6) Soil types within each location should be consistent.

(7) The sites should be within a one-hundred mile radius from Sacramento.

(8) Landscape maintenance personnel responsible for the selected sites need to be enthusiastic about the prospect of using moisture sensors.

Two sites were located that met all of the above; Site 1, along US 50 in Sacramento and Site 2, along Route 24 in Oakland (Figure 8.1).

The manufacturers and/or dealers of the four sensors, Watermark, Hydrovisor, Hydrodyne, and Watermatic, were contacted to obtain new, off-the-shelf sensors for installation at the two study sites. Two sensors were obtained from each, except Watermatic. Conversations with the dealer (located in Southern California) marketing the Australian based Watermatic moisture sensor led the researchers to believe that the manufacturer was having difficulty with his company and might not be able to supply sensors in the future. With the consent of all research coordinators, the Watermatic moisture sensor was dropped from the study at this time.

8.1 Sacramento Field Investigation

8.1.1 Site Description

Site 1 of the field investigation study was located along the south side of US 50, between the 39th Street undercrossing and the 59th Street off-ramp, near downtown Sacramento. Although the location only offered a north facing slope, ample room existed at the top of slope where the sensors were installed. The south facing slope of US 50 at this location was not an acceptable site due to the excessive amount of hardpan present on the cut slope face. No hardpan was encountered on the north facing slope.

The vegetation throughout the site consisted primarily of ice plant with ivy located under the overcrossings at 48th and 51st Streets, and a variety of 10 to 30 foot tall trees situated along the top of the slope. The ivy and trees were watered with separate irrigation systems independent of the ice plant irrigation systems. Figures 8.2 and 8.3 are typical of Site 1.

Three independently operated Griswald automatic controllers, F, G, and I, were used to control the irrigation systems at the Sacramento field investigation location. Rainbird over head impact sprinklers, 14 to 16 per valve,

Field Investigation Sites

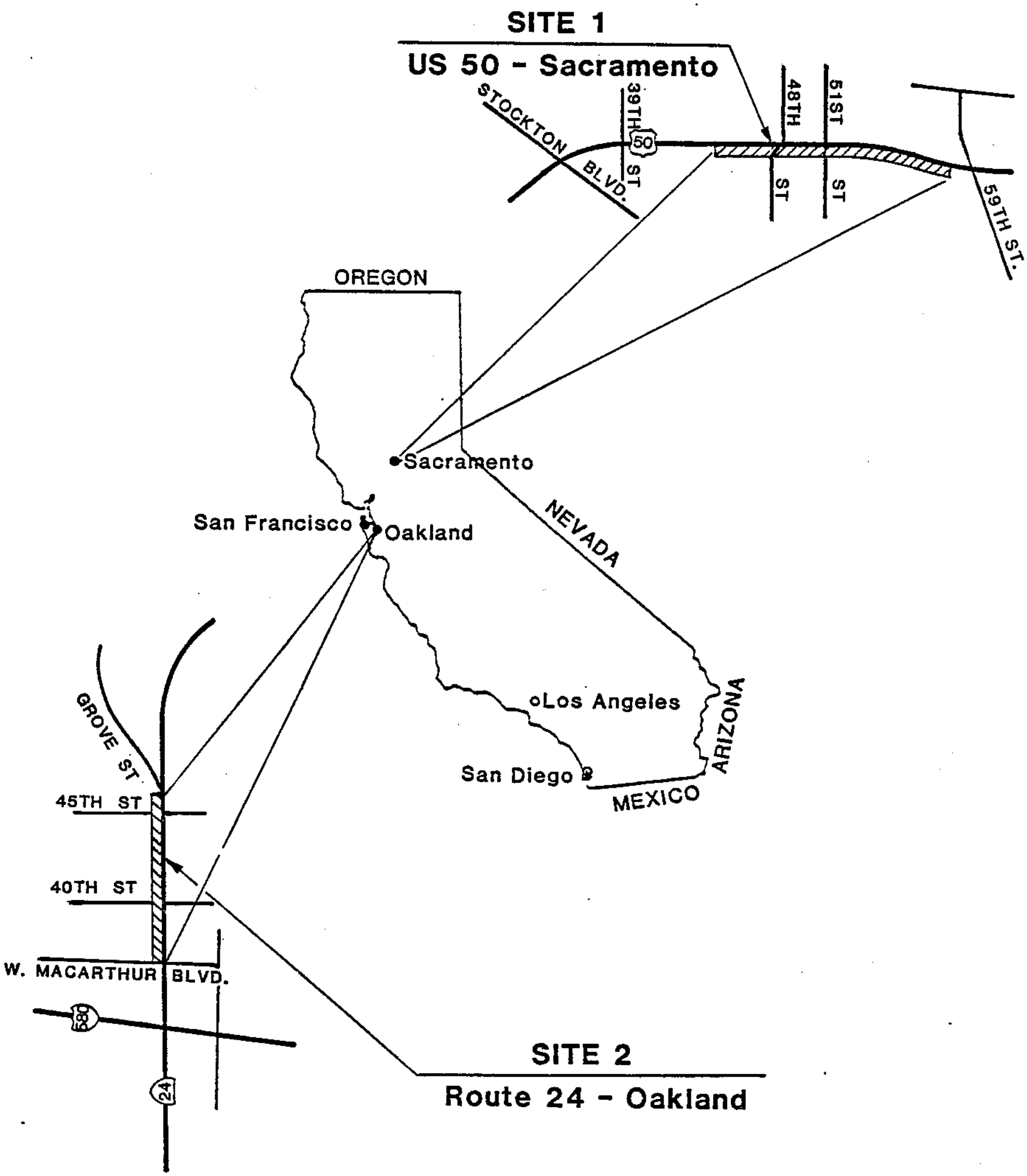


FIGURE 8.1

Figure 8.2
Typical View of Sacramento Site

Figure 8.3
Typical View of Sacramento Site

were used throughout the site. The measured output halfway between two sprinklers ranged from 0.21 to 0.35 inches per hour.

Soil analyses at the three sensor locations and the control section were performed (Figure 8.4). The soil at all of the sensor locations were relatively consistent ranging from loam to silty loam.

8.1.2 Sensor Installations

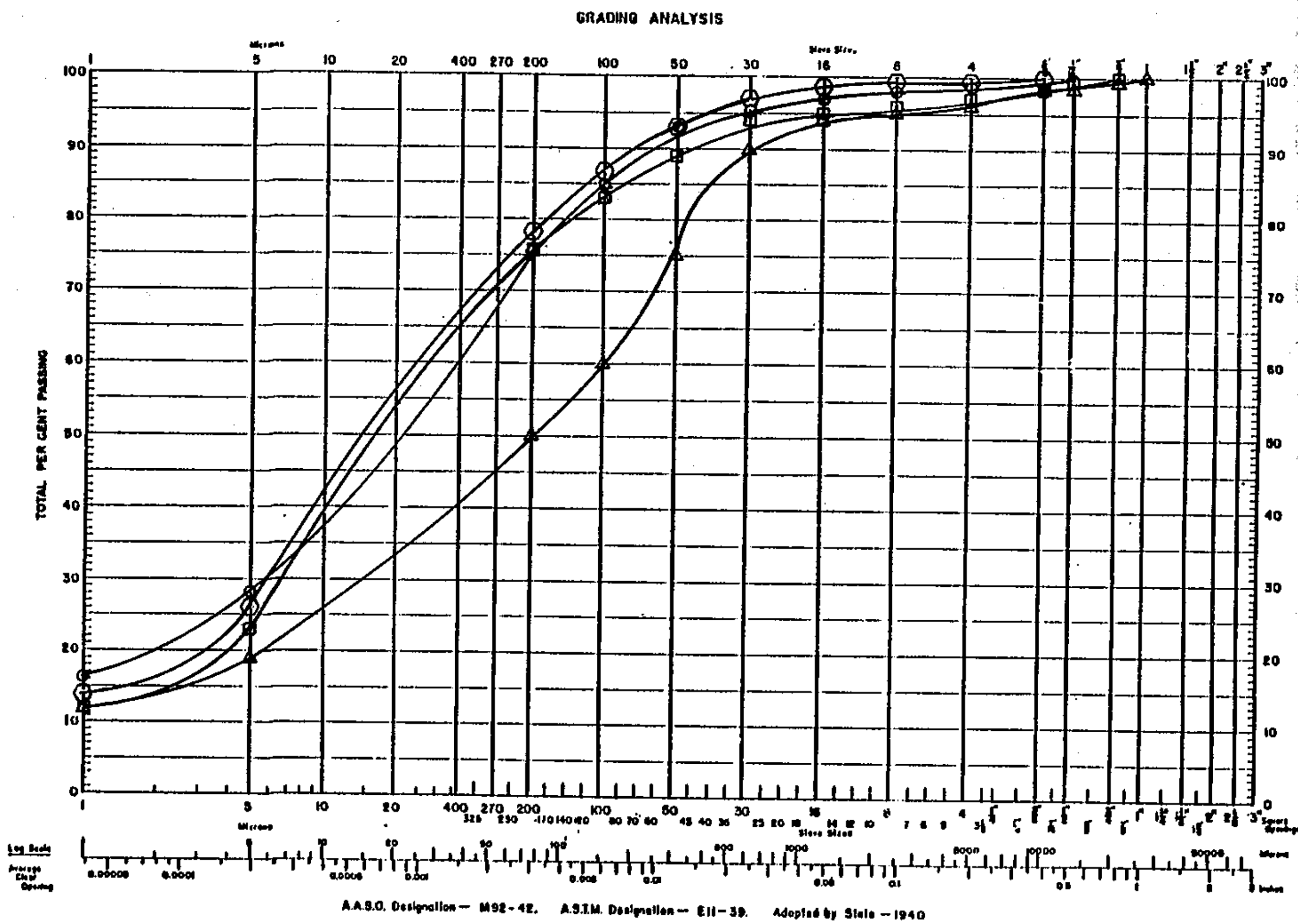
On June 2 and 3, 1986 the three sensors, Hydrovisor Hydrodyne, and Watermark, were installed at their selected locations (Figure 8.5), within the active root zone of the ice plant at a depth of three inches. Locations which received water from two impact sprinklers were chosen as the best suited locations for the sensors. Manufacturer directions were followed on the installation procedures.

On June 13, 1986, after allowing for an acclimatization period the sensors were connected to their respective irrigation valves: A 20-30 cb Hydrovisor moisture sensor was connected to valve F-10. The Hydrodyne sensor, originally set at a moisture level of 65-75 percent was connected to valve G-11. The Watermark sensor was connected to valve I-4 and set at the 35 cb level. The control section, irrigated by valve I-2 was used as a comparison, to monitor the quality and aesthetics of the vegetation, with the other three test locations.

Two 24-volt timers were used at each location to monitor the amount of time that the valve was scheduled to operate (allotted) and the actual amount of time that the sensor was allowing the valve to operate (actual).

No complications or unforeseen problems were encountered with any of the connections or installation procedures.

Landscape maintenance personnel were briefed on the usage of the sensors and were instructed to contact the research personnel if any water deficiencies were noticed or if any changes were made to the irrigation schedules.

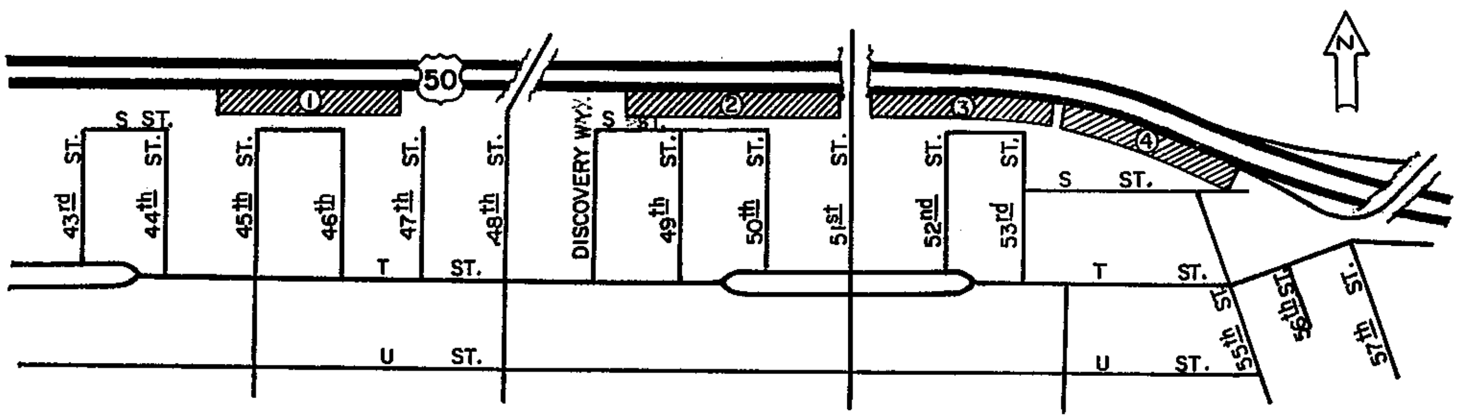


△ HYDROVISOR □ HYDRODYNE ○ WATERMARK ⬡ CONTROL

SACRAMENTO FIELD INVESTIGATION
SOIL GRADING ANALYSES

FIGURE 8.4

Moisture Sensor Location Map
Sacramento Field Investigation



NOTE: SHADED AREAS DENOTE WATERING AREAS CONTROLLED BY RESPECTIVE SENSOR

① HYDROVISOR ② HYDRODYNE ③ CONTROL ④ WATERMARK

FIGURE 8.5

8.1.3 Results

Site inspections were conducted on a weekly basis beginning June 13, 1986 and continued until the first substantial rainfall on October 21, 1986. At this time the irrigation controllers were programmed with the winter schedule. At each inspection the 24-volt timer readings were taken and the sensors were checked to verify that all were operating properly.

During a three week period, from September 15 until October 6, the electricity and water were turned off. A break in a water pipe servicing the area which included the test locations required repairs before operations could resume.

The data obtained from the three moisture sensor locations and at the control section are tabulated in Tables 8.1, 8.2, 8.3, and 8.4 and graphically depicted in Figures 8.6 and 8.7. No maintenance or operational related problems were encountered with any of the sensing units during the investigation period.

The Hydrovisor moisture sensor allowed for irrigation to occur a total of 3,191 minutes of the allotted 3,556 minutes giving an overall savings of 10 percent. Being a preset sensor, adjustments to the unit could not be made. The only variation that might have been performed, but was not, was to either raise or lower the sensing tip to adjust for the water requirements.

The Watermark sensor originally set a 35 cb level was adjusted to the 60 cb setting on July 7, after it was noted that the soil had ample moisture and no water savings had occurred. The adjustment was performed to determine which setting would allow for sufficient irrigation needs without jeopardizing the health and aesthetics of the vegetation. The data in Table 8.2 showed that a significant water savings occurred during the next several weeks.

Table 8.1

Sacramento Field Investigation Data - Hydrovisor

DATE	CONTROLLER READINGS (HOURS)	VALVE READINGS (HOURS)	ELAPSED TIME FROM LAST CONTROLLER READING (MINUTES)	ELAPSE TIME FROM LAST VALVE READING (MINUTES)	PERCENT REDUCTION
6-13-86	2.125	1.650	---	---	--
6-16-86	2.875	2.350	45	42	7
6-23-86	4.300	3.750	86	84	2
6-30-86	6.925	6.300	158	153	3
7-07-86	9.575	8.875	159	155	3
7-15-86	12.850	12.050	197	191	3
7-21-86	15.150	14.275	138	134	3
7-28-86	18.400	17.475	195	192	2
8-04-86	20.725	19.700	140	134	4
8-12-86	23.675	22.550	177	171	3
8-18-86	27.100	25.875	206	200	3
8-26-86	34.100	32.700	420	410	2
9-02-86	41.050	39.450	417	405	3
9-08-86	48.150	43.975	426	272	36
9-15-86	56.000	49.725	471	345	27
9-23-86	56.350	50.050	21	20	5
9-29-86	56.350	50.050	0	0	0
10-07-86	57.950	51.575	96	92	4
10-14-86	60.400	53.850	147	137	7
10-21-86	61.350	54.750	57	54	5
TOTALS			3556	3191	10

Notes: (1) A preset, 35 cb Hydrovisor unit installed 6-13-86
(2) Power to irrigation system from 9-15-86 to 10-6-86.

Table 8.2

Sacramento Field Investigation Data - Watermark

DATE	CONTROLLER READINGS (HOURS)	VALVE READINGS (HOURS)	ELAPSED TIME FROM LAST CONTROLLER READING (MINUTES)	ELAPSED TIME FROM LAST VALVE READING (MINUTES)	PERCENT REDUCTION
6-13-86	2.150	2.150	---	---	---
6-16-86	3.800	3.775	99	98	1
6-23-86	6.275	6.250	149	149	0
6-30-86	9.525	9.500	195	195	0
7-07-86	12.825	12.800	198	198	0
7-15-86	17.125	16.075	258	197	24
7-21-86	20.400	19.350	197	197	0
7-28-86	23.675	21.400	197	123	38
8-04-86	33.925	24.900	615	210	66
8-12-86	45.800	28.425	713	212	70
8-18-86	51.200	29.100	324	41	87
8-26-86	63.250	33.875	723	287	60
9-02-86	71.275	36.775	482	174	64
9-08-86	79.000	40.275	464	210	55
9-15-86	90.525	42.850	692	155	78
9-23-86	90.525	42.850	0	0	0
9-29-86	90.525	42.850	0	0	0
10-07-86	91.800	44.100	77	75	3
10-14-86	93.850	46.150	123	123	0
10-21-86	96.900	49.200	183	183	0
TOTALS			5689	2827	50

Notes: (1) Moisture level set at 35 cb on 6-13-86.
(2) Moisture level lowered to 60 cb on 7-7-86.
(3) Power off to irrigation system form 9-15-86 to 10-6-86.

Table 8.3

Sacramento Field Investigation Data - Hydrodyne

DATE	CONTROLLER READINGS (HOURS)	VALVE READINGS (HOURS)	ELAPSED TIME FROM LAST CONTROLLER READING (MINUTES)	ELAPSED TIME FROM LAST VALVE READING (MINUTES)	PERCENT REDUCTION
6-13-86	1.350	1.350	---	---	---
6-16-86	1.475	1.475	8	8	0
6-23-86	3.625	3.575	129	126	2
6-30-86	7.150	6.050	212	149	30
7-07-86	12.050	9.550	294	210	29
7-15-86	17.625	12.575	335	182	46
7-21-86	21.050	14.825	206	135	34
7-28-86	24.400	16.100	201	77	62
8-04-86	27.450	17.150	183	63	66
8-12-86	31.575	18.650	248	90	64
8-18-86	33.650	19.300	125	39	69
8-26-86	41.250	22.775	456	209	54
9-02-86	46.600	24.700	321	116	64
9-08-86	53.550	28.400	417	222	47
9-15-86	62.400	31.225	531	170	68
9-23-86	62.400	31.225	0	0	0
9-29-86	62.400	31.225	0	0	0
10-07-86	63.600	32.400	72	71	1
10-14-86	65.050	33.750	87	81	7
10-21-86	69.750	35.050	282	78	72
TOTALS			4107	2026	51

Notes: (1) Moisture level set at 65-75 percent on 6-13-86.
(2) Moisture level lowered to 50-60 percent on 6-23-86.
(3) Moisture level raised to 60-70 percent on 8-18-86.
(4) Power to irrigation system was off from 9-15-86 to 10-6-86.

Table 8.4

Sacramento Field Investigation Data - Control

DATE	CONTROLLER AND VALVE READINGS (HOURS)	ELAPSED TIME FROM LAST READING (MINUTES)
6-13-86	2.775	---
6-16-86	3.800	62
6-23-86	6.250	147
6-30-86	9.525	197
7-07-86	12.800	197
7-15-86	17.300	270
7-21-86	20.525	194
7-28-86	23.750	194
8-04-86	26.450	162
8-12-86	30.100	219
8-18-86	31.750	99
8-26-86	35.100	201
9-02-86	37.400	138
9-08-86	39.400	120
9-15-86	42.400	180
9-23-86	42.400	0
9-29-86	42.400	0
10-07-86	42.750	21
10-14-86	43.700	57
10-21-86	45.000	78
TOTAL		2,536

Notes: (1) Power to irrigation system was off from 9-15-86 to 10-6-86.

MOISTURE SENSOR IRRIGATION TIMES
Sacramento Field Investigation
June 16 - October 21, 1986

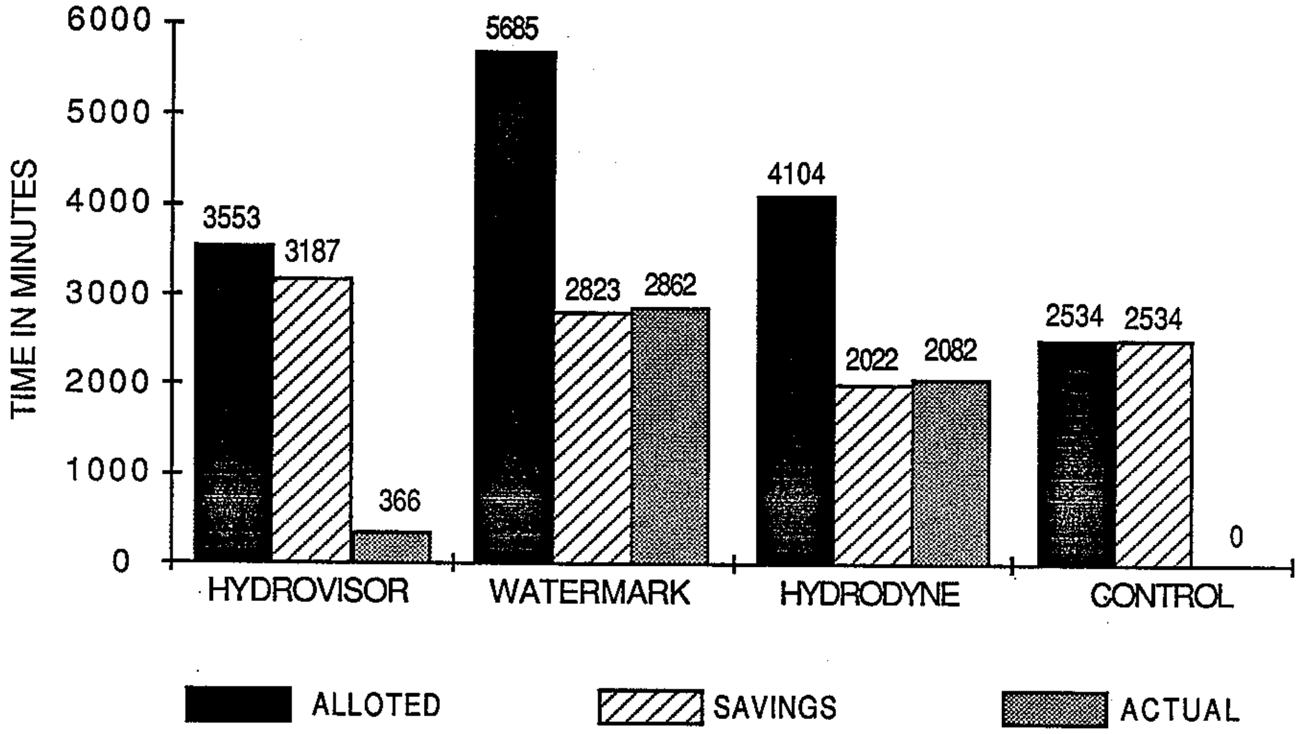
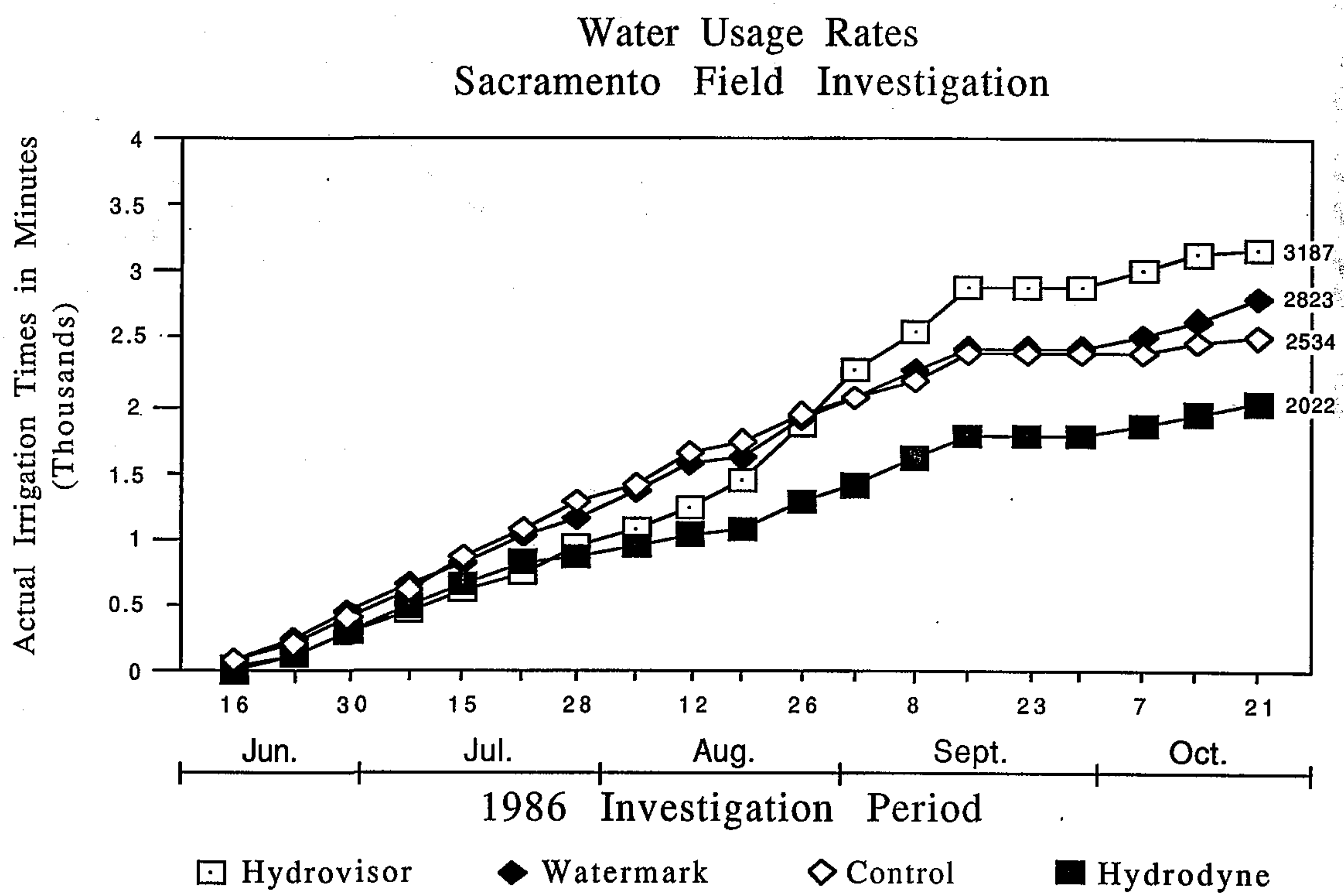


FIGURE 8.6



Water Usage Rates
Sacramento Field Investigation
Actual Irrigation Times in Minutes (Thousands)
4
3.5
3
2.5
2
1.5
1
0.5
0
3187
2823
2534
2022
16
30
15
28
12
26
8
23
7
21
Jun.
Jul.
Aug.
Sept.
Oct.
1986 Investigation Period
Hydrovisor
Watermark
Control
Hydrodyne

FIGURE 8.7

In late July landscape maintenance increased the allotted time on the controller evident by the large increase in controller readings in Table 8.2. Even though the controller allotted times increased, the actual irrigation times remained relatively constant. A total irrigation time of 2827 minutes was recorded by the 24-volt timer as opposed to a total allotted time of 5689 minutes. Using these values a reduction of almost 50 percent was noticed, however this is an unrealistic value due to the large increase in the allotted irrigation time. This is further discussed in the next section.

The Hydrodyne moisture sensor was originally set at a 65-75 percent moisture level but was adjusted on June 23 to the 50-60 percent level. Although savings of up to 69 percent were achieved over the next eight week period, the vegetation became stressed and the soil dried out substantially. On August 18, the moisture setting was increased to the 60-70 percent level which corrected the deficiency. Maintenance personnel also increased the allotted time on the controller about the same time. The actual watering time for the 131 day test period was 2,026 minutes while the allotted time was 4,107 minutes leading to a 51 percent reduction.

The control section was used as a comparison with the other test sections. The data in Table 8.4 showed that the elapsed time from one reading to the next remained relatively constant throughout the test period totaling 2,536 minutes by the end of the investigation.

Visual inspections of the test areas were conducted throughout the investigation. As previously stated, the vegetation in the Hydrodyne section appeared stressed during the course of the investigation but once the moisture level was increased, the plants rehydrated and appeared healthy and undamaged. The control and Hydrovisor sections showed no signs of any stress occurring during any part of the investigation. The majority of the iceplant at the Watermark test section appeared to have received sufficient irrigation throughout the test period, however, several specific areas appeared stressed and to have not received sufficient moisture. These deficiencies appeared likely to have been caused by inadequate coverage of the impact sprinklers as opposed to improper adjustment of the sensor.

8.1.4 Discussion of Results

All three sensors showed encouraging results as to their usage within a highway landscape environment. No installation, operation, or maintenance related problems were encountered with any of the units and water savings as compared to the respective allotted times were noted with all sensors.

Theoretically the four locations serviced by the separate irrigation valves were identical and should have obtained equal amounts of irrigation time. The data in Figure 8.6 showed that this was not the case. The reason for the large variation in allotted times was due to the increase in schedules only on certain stations of the controllers. In subsequent conversations with landscape maintenance personnel, they stated that they had noticed that several locations within the vicinity appeared not to be receiving adequate water and increased the times accordingly. They stated that they were unaware that the sensors were regulating the irrigation cycles and had assumed the controllers were malfunctioning. Although the landscape personnel were contacted at the onset of the testing program, personnel changes occurred during the summer months and the new employees were unaware of the situation and failed to contact the research personnel on controller time changes.

Even though there were large variations in the allotted times, the actual watering times did not vary as dramatically. As compared to the control, the Watermark and Hydrovisor allowed for 11 and 26 percent more water, respectively while the Hydrodyne usage was 20 percent less. However, the vegetation at the Hydrodyne test section was experiencing an excessive amount of stress that probably would have allowed for degradation of the vegetation if the moisture level had not been corrected.

Although the Watermark and Hydrovisor moisture sensors allowed for more water than what the control irrigated, this investigation showed that these moisture sensors successfully regulated the water usage even when excessive scheduling was allowed. It appears that at this location the scheduled amount of time on the control section was adequate and that if sensors were installed savings from 10 to 20 percent might be expected.

8.2 Oakland Field Investigation

8.2.1 Site Description

Site 2 of the field investigation study was located along the State Route 24 between the 45th Street and the MacArthur Boulevard undercrossings near downtown Oakland (Figure 8.1). This site offered a western facing slope in a mild climatic area. Figures 8.8 and 8.9 are typical of site 2.

The vegetation along the upper one half of the slopes was primarily iceplant with a scattering of well established shrubs and trees. The lower one-half was dominated primarily by large shrubs and trees with intermittent patches of iceplant. The majority of the vegetation appeared healthy with a few areas which had either been damaged in vehicular accidents or had died back by not receiving sufficient irrigation. This appeared to be caused by improper sprinkler coverage as opposed to insufficient watering times.

Four automatic Griswald controllers were used to operate the irrigation system at Site 2. The master controller D, located on the east side of Route 24, was used to supply power to several satellite controllers in the adjacent area. Three of these satellite controllers were used in the test section, D9-A, D11-I, and D11-J. Rainbird overhead impact sprinklers, 6 to 9 per valve were used throughout the test site. The measured water output halfway between two sprinklers ranged from 0.40 to 0.65 inches per hour.

Figure 8.8
Typical View of Oakland Site

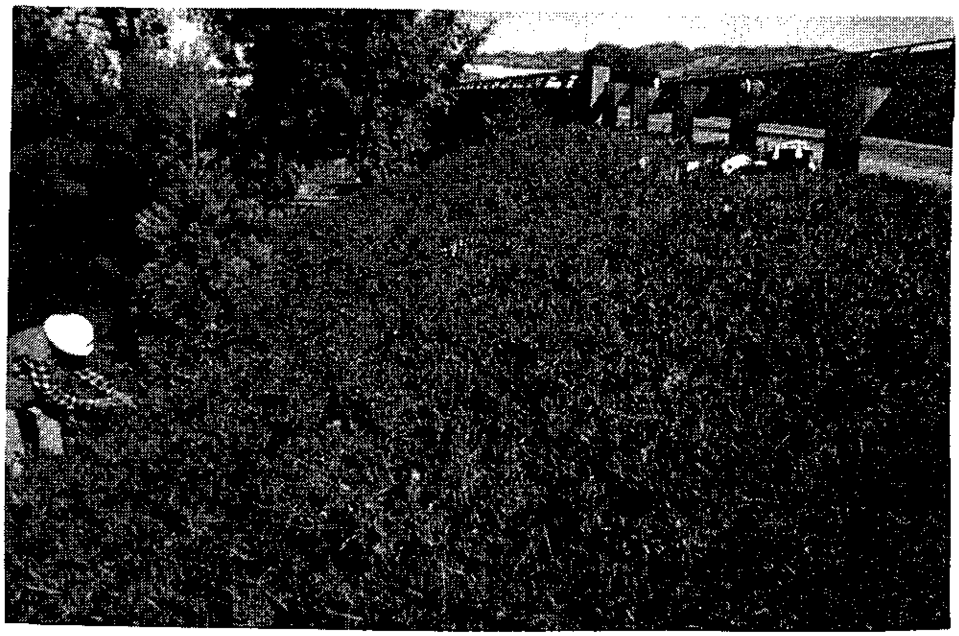


Figure 8.9
Typical View of Oakland Site

Soil analyses at the four locations were performed. The soil at the sites ranged from a sandy clayey loam to a loam as determined by the data shown in Figure 8.10.

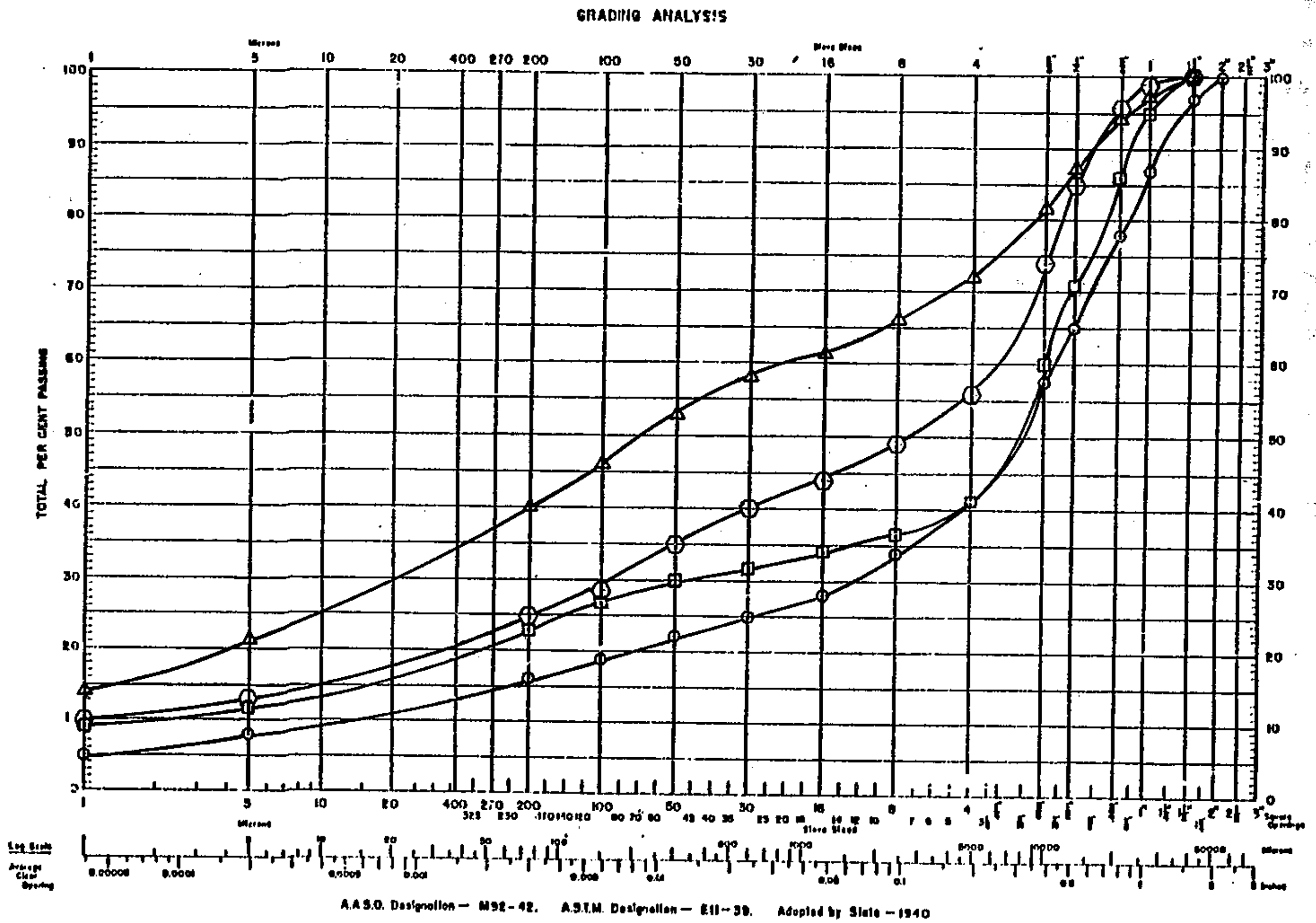
8.2.2 Sensor Installations

On May 21, 1986 the three sensors, Hydrovisor, Watermark and Hydrodyne, were installed at their selected locations (Figure 8.11), within the active root zone of the ice plant at a depth of three inches. Locations which received water from two impact sprinklers were chosen as the best suited locations for the sensors. Manufacturer directions were followed on the installation procedures.

On June 19, 1986, after allowing for an acclimatization period the sensors were connected to their respective irrigation valves: A 20-30 cb Hydrovisor moisture was connected to valve D9-A2. The Watermark sensor was connected to valve D11-J1. The Hydrodyne sensor, originally set at 45-55 percent, was connected to valve D11-I2. The control section, irrigated by valve D-1, was used as a comparison to monitor the quality and aesthetics of the vegetation with the other three test locations.

Two 24-volt timers were used at each location to monitor the amount of time that the valve was scheduled to operate and the actual amount of time that the sensor was allowing the valve to operate. The electrical connections were identical to those used in the Sacramento field investigation.

No complications or unforeseen problems were encountered with any of the connections or installation procedures. At the time of the installation it was discovered that there was no electrical power at two of the stations, D-1 and D11-J1. Maintenance personnel were notified of this problem at that time. The electrical problems were not corrected until July 23, 1986 at which time the testing at Site 2 began.

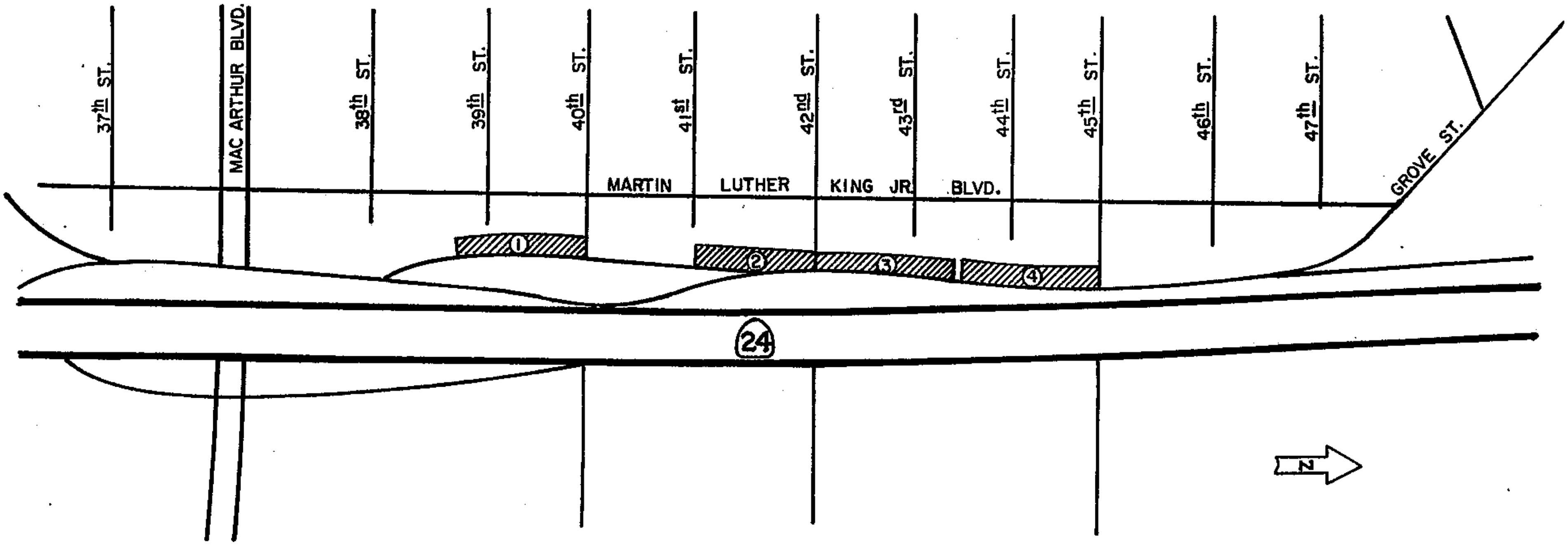


△ HYDROVISOR □ HYDRODYNE ○ WATERMARK ⬡ CONTROL

OAKLAND FIELD INVESTIGATION
SOIL GRADING ANALYSES

FIGURE 8.10

Moisture Sensor Location Map
Oakland Field Investigation



NOTE: SHADED AREAS DENOTE WATERING AREAS CONTROLLED BY RESPECTIVE SENSOR

① HYDROVISOR ② CONTROL ③ HYDRODYNE ④ WATERMARK

FIGURE 8.11

8.2.3 Results

Site inspections were conducted on a weekly basis beginning July 23, 1986 and continued until the first substantial rainfall on November 6, 1986, with the exception of the first weeks in August and September and the third week in October. At each inspection the 24-volt timer readings were taken and the sensors were checked to verify that all were operating properly.

During a one-week period from September 24 through September 30, the electricity to the entire system was turned off for reasons unknown.

The data obtained from the three moisture sensor locations and at the control section are tabulated in Tables 8.5, 8.6, 8.7, and 8.8, and graphically depicted in Figures 8.12 and 8.13. No maintenance or operation related problems were encountered with any of the sensing units during the investigative period. On the final inspection, November 6, the Hydrodyne moisture sensor was discovered to be laying on top of the ice plant. In conversations with landscape personnel, it was discovered that laborers used to remove highway litter had gone through the area and inadvertently unearthed the sensing unit. In actual field conditions this would not be a problem because all of the wires connecting the sensor would be buried, and markers that were used in the study to designate the locations of the sensors would not be present.

The Hydrovisor 20-30 cb moisture sensor allowed for irrigation to occur a total of 958 minutes of the allotted 1281 minutes giving an overall savings of 25 percent (Table 8.5). No adjustments of any kind were made on the present sensor.

The Watermark sensor was originally set at the 60 cb level. On August 20, the sensing level was decreased to the 35 cb setting. At the time of the adjustment the ice plant did not appear stressed but the soil was visually too dry. To this time the sensor had only allowed irrigation of 127 minutes of the 346 minutes allotted to the valve indicating a 75 percent time savings (Table 8.6). By adjusting the moisture level on the sensor

Table 8.5

Oakland Field Investigation Data - Hydrovisor

DATE	CONTROLLER READINGS (HOURS)	VALVE READINGS (HOURS)	ELAPSED TIME FROM LAST CONTROLLER READING (MINUTES)	ELAPSED TIME FROM LAST VALVE READING (MINUTES)	PERCENT REDUCTION
7-23-86	7.925	7.600	---	---	---
7-31-86	9.350	9.000	86	84	2
8-13-86	12.650	12.250	198	195	2
8-20-86	14.100	13.500	87	75	14
8-28-86	15.150	14.525	63	62	2
9-11-86	16.950	16.275	108	105	3
9-15-86	18.250	17.150	78	53	32
9-24-86	19.675	17.500	86	21	76
9-30-86	19.675	17.500	0	0	0
10-16-86	24.950	20.500	317	180	43
11- 6-86	29.250	23.550	258	183	29
TOTALS			1281	958	25

Notes: (1) A preset 35 cb unit was originally installed.
(2) Power to system was off from 9-24-86 to 9-30-86.

Table 8.6

Oakland Field Investigation Data - Watermark

DATE	CONTROLLER READINGS (HOURS)	VALVE READINGS (HOURS)	ELAPSED TIME FROM LAST CONTROLLER READING (MINUTES)	ELAPSED TIME FROM LAST VALVE READING (MINUTES)	PERCENT REDUCTION
7-23-86	1.350	0.375	---	---	--
7-31-86	3.000	0.675	99	18	82
8-13-86	5.775	2.150	167	89	47
8-20-86	7.100	2.475	80	20	75
8-28-86	8.250	3.250	69	47	32
9-11-86	10.600	5.600	141	141	0
9-15-86	11.250	6.250	39	39	0
9-24-86	12.600	6.575	81	20	75
9-30-86	12.600	6.575	0	0	0
10-16-86	17.650	6.600	303	2	99
11- 6-86	21.700	7.150	243	33	86
TOTALS			1222	409	67

Notes: (1) Moisture level set at 60 cb on 7-23-86.
(2) Moisture level raised to 35 cb on 8-20-86.
(3) Power to system was off from 9-24-86 to 9-30-86.

Table 8.7

Oakland Field Investigation Data - Hydrodyne

DATE	CONTROLLER READINGS (HOURS)	VALVE READINGS (HOURS)	ELAPSED TIME FROM LAST CONTROLLER READING (MINUTES)	ELAPSED TIME FROM LAST VALVE READING (MINUTES)	PERCENT REDUCTION
7-23-86	6.525	3.425	---	---	--
7-31-86	8.050	4.450	92	62	33
8-13-86	10.500	5.300	147	51	65
8-20-86	11.675	5.550	71	15	79
8-28-86	13.100	6.050	86	30	65
9-11-86	14.600	6.650	90	36	60
9-15-86	15.200	6.975	36	20	44
9-24-86	16.400	7.200	72	14	81
9-30-86	16.400	7.200	0	0	0
10-16-86	20.950	7.450	273	15	95
11-06-86	---	---	--	--	--
TOTALS			867	243	72

Notes: (1) Moisture level set at 45-55 percent on 7-23-86.
(2) Power to system was off from 9-24-86 to 9-30-86.
(3) Sensing unit inadvertently damaged by roadway crews during October.

Table 8.8

Oakland Field Investigation Data - Control

DATE	CONTROLLER AND VALVE READINGS (HOURS)	ELAPSED TIME FROM LAST READING (MINUTES)
7-23-86	0.000	---
7-31-86	0.550	33
8-13-86	2.000	87
8-20-86	3.325	80
8-28-86	4.375	63
9-11-86	6.075	102
9-15-86	6.750	41
9-24-86	8.150	84
9-30-86	8.150	0
10-16-86	13.600	327
11-06-86	17.700	246
TOTAL		1,063

Notes: (1) Power to system was off from 9-24-86 to 9-30-86.

MOISTURE SENSOR IRRIGATION TIMES
Oakland Field Investigation
July 23 - November 6, 1986

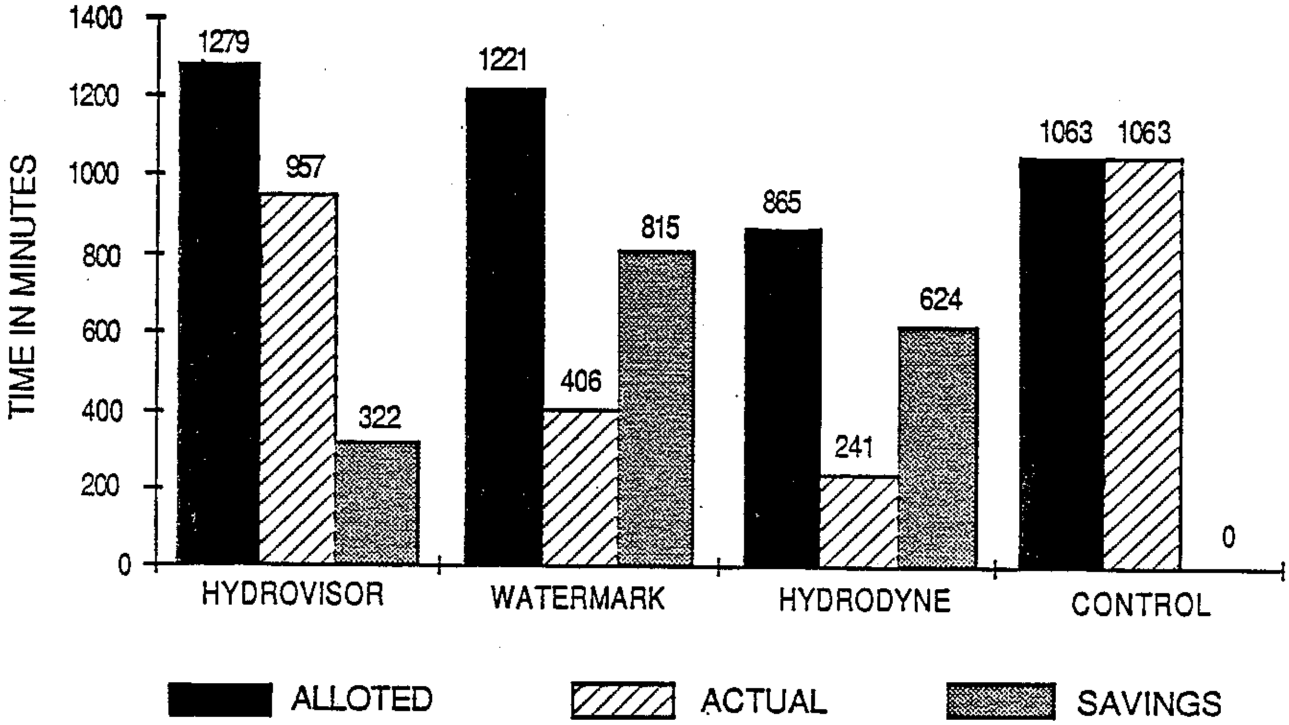


FIGURE 8.12

Water Usage Rates
Oakland Field Investigation

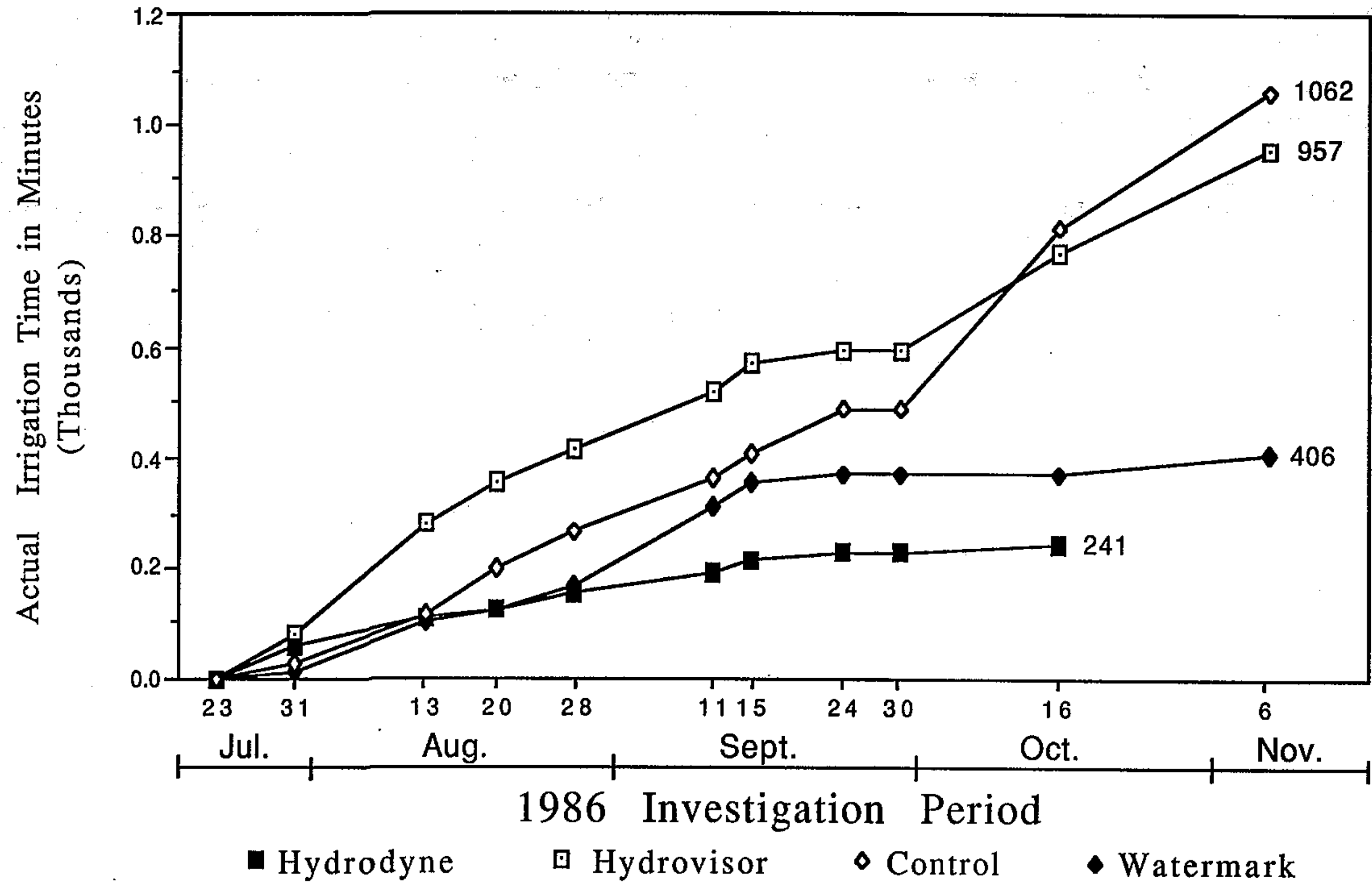


FIGURE 8.13

additional irrigation time should have occurred, however, the overall savings at the end of the test period still indicated a 67 percent reduction. Although the soil appeared dry, the vegetation appeared healthy.

The Hydrodyne moisture sensor was originally set at a 45-55 percent moisture level and remained at this setting through out the testing period. As previously mentioned, the sensing unit was unearthed sometime in late October or early November by litter removal crews. Therefore the last reading of value would be the October 16 reading. At this time the sensor had allowed only 243 minutes of irrigation of the 867 minutes allotted by the controller (Table 8.7). As with the Water mark location, the soil appeared dry but the vegetation did not appear damaged or stressed. The overall savings at the end of the test period indicated a 72 percent reduction.

The control section was used as a comparison with the other test sections. From Figure 8.12 it can be seen that the allotted time remained constant except during the end of September and the first two weeks of October. A total of 1063 minutes was allotted to the control section during the course of the investigation.

Visual inspections of the test areas were conducted through out the investigation. Previous to the investigation, several specific areas had died off as a result of improper sprinkler coverage, but at no time during the testing period did any of the vegetation appear to have been stressed or damaged even though the soil at the Watermark and Hydrodyne test sections was dry.

8.2.4 Discussion of Results

All three sensors showed encouraging results as to their usage within a highway landscape environment. There were no installations, operation or maintenance related problems encountered with any of the units during the investigative period. Water savings were noted in all three sensors when compared to that of the control section. Unlike that of the Sacramento field investigation, the allotted times of all three test sections at the Oakland field site were relatively consistent.

Figure 8.13 shows it can be seen that all three sensors allowed for less water usage then did the control section. The Hydrovisor sensor, showing the least amount of savings still produced a 25 percent reduction over the allotted time. The Watermark and Hydrodyne posted 67 and approximately 70 percent reductions respectively. Although no visible signs of hydration were noted to have occurred at either the Hydrodyne or Watermark test sections, the soil was dry and if allowed to continue for much longer, might have incurred enough stress to allow disease to infest the vegetation. It appears that at the Oakland investigation section, the scheduled amount of time on the individual irrigation valves was in excess of what is actually required by the vegetation. If sensors were installed, savings over the existing schedule of up to 50 percent could be expected. Unlike that of the Sacramento field investigation, the allotted times of all three test sections at the Oakland field site were relatively consistent.

9. GUIDELINES

The following guidelines are for the use of one moisture sensor per irrigation valve.

1) Determine which valves are to receive moisture sensors.

   Moisture sensors can be used with any electrically operated, 24-volt irrigation valve with any kind of distributions system, i.e., overhead impact, bubbler, drip, etc. Moisture sensors must be located within the watering area of the valve with which it is to be connected.

   Certain areas may not be suitable for the installation of moisture sensors. These include locations where the valve and sensor are separated by the roadway or sidewalk, and irrigation systems in which booster pumps are utilized. Not all pump systems will be affected, however, a site investigation must be conducted to determine if excessive or insufficient pressure will be generated if several of the valves within the system remain closed.

2) Determine location for moisture sensor.

   Overhead impacts: Select a location in which the soil is neither extremely wet nor dry and will receive the maximum amount of sunlight exposure. On slopes, locate sensor as high as feasible while staying within a sprinkler overlap area. On level ground, locate the sensor in an overlap area and in a location where water will not accumulate or collect.

   Drip and bubblers: Locate sensor in an area which will receive water from the emitter but do not place it directly under emitter orifice. Select an area which will receive the maximum amount of sunlight exposure.

3) Determine depth of sensor.

For proper moisture sensor operation and plant development, the depth at which the sensor is originally installed is most critical. In general, the recommended depth is 1/3 to 1/2 the root zone depth, with a two-inch minimum. However, the depth will vary with plant type, age of plant and past watering practices. For example, for newly planted vegetation, shallowed-rooted plants and areas that have historically only been shallowly irrigated, the sensor depth will need to be near the surface, so as not to over stress the vegetation. As the root zone begins to develop and deepen the sensors might need to be lowered to stay at the proper root depth.

Contact the Office of Highway Maintenance or Landscape Architecture for recommendations.

4) Determine which moisture sensors are to be used.

This depends upon personal preference (see Tables 7.2, 7.4 and 7.5 for information on installation maintenance and overall rating of the sensors). All three sensors investigated in the study provided satisfactory results.

5) Installation procedures.

Sensor burial and wire size shall conform to manufacturers recommendations.

Electrical connections shall conform to manufacturer's recommendations.

Backfill material around sensor shall be the removed native soil, free of rocks and stones, and shall be firmly compacted to prevent puddling or ponding of water.

All splices shall be underground, water-tight connections.

All wires shall be buried a minimum of 12 inches.

The installation of two 24-volt timers used to monitor the controller allotted and valve activated times is recommended but not required. This information is useful in determining water savings and detecting electrical problems with controllers or sensors.

The installation of an override switch is required if the Watermark moisture sensor is being used.

Mark the exact location of the sensors and wire connections on the irrigation maps located inside the controller cabinets. Make a copy and keep in the landscape maintenance field office.

6) Adjustment of moisture sensors.

Adjustment of the sensor is site specific and depends upon the soil type, density and permeability. If installing:

Watermark; using the 34 cb setting is normally adequate for most soil types, or use the 15 cb setting for sandy soils or the 60 cb for heavy clay soils. After allowing for several irrigation cycles, inspect the area and adjust moisture settings up or down, if required. If after adjusting the settings, the soil is still too wet or dry, adjust the controller allotted or if the situation dictates physically relocate the sensor up or down.

Hydrovisor; install appropriate sensor taking into account the soil properties. The 20-30 cb sensor is adequate for most types of soil. Consider using the 8-12 cb sensor in sandy soils or 40-50 cb model in heavy soils. If further adjustments are required, change times on controllers or relocate sensor.

Hydrodyne; once the sensor is installed, determine the existing soil moisture reading from meter and adjust high and low settings accordingly, following the manufacturers instructions. Use a 5 to 10 percent differential between the high and low settings. The greater the difference, the drier the soil will become between irrigation cycles.

7) Check sensor for proper operation.

Once installed and initially adjusted, verify the operation of the sensor. If the sensor is dry and the valve is activated irrigation should commence. Turn controller off and wet sensor by pouring water over area in which sensor is buried. Recheck by actuating valve station. It should not come on. Switch sensor to override mode and irrigation should begin. If the sensor is already wet, activate valve. The sensor should not allow for irrigation to begin. Then switch the sensor to the override position which should allow watering to begin. If this occurs, all is operating properly.

Be sure to set override switch back to the operational mode.

8) Adjustment of controllers.

If an adequate and proper irrigation schedule has previously been developed and employed for each valve, there should be no need to change the times on the controller.

9) Maintenance of sensors.

Once the initial adjustment of the sensors has been completed and if the sensors are properly installed, there should be no special maintenance requirements. However, maintenance personnel should inspect sensors periodically as they would other irrigation equipment.

10. REFERENCES

1. Storm, D.E. and T.M. Younos, Evaluation of Soil-Moisture Sensors for Use in Data Acquisition Systems - A Technical Guide, Virgina Polytechnic Institute and State University, College of Agriculture and Life Sciences, Information Series 84-4, December, 1984.

2. Prebble, R.E., et al., Field Installation and Maintenance -Neutron Soil Moisture Meter, East Melbourne, Victoria, Australia, 1981.

3. Jackson, R.D., Soil Moisture Inferences From Thermal Infrared Measurements of Vegetative Temperatures, US Department of Agriculture and NASA, 1981.

4. White, J.G. ed., "Corn Plants 'Schedule' Their Own Irrigation Via Sensors," Irrigation Age, pg. 4-5, July-August 1986.

5. Whitney, M., F.D. Gardner and L.J. Briggs, "An Electrical Method of Determining the Moisture Content of Arable Soils," Dept. Bulletin No. 6, US Department of Agriculture, 1897.

6. Bouyoucos, G.J. and A.H. Mick, "An Electrical Resistance Method for the Continuous Measurement of Soil Moisture Under Field Conditions," Michigan Technical Bulletin 172, pg. 1-38, 1940.

7. Coleman, E.A. and T.M. Hendrix, "The Fiberglass Electrical Soil-Moisture Instrument," Soil Science, 67(6), pg. 425-438, 1949.

8. Bouyoucos, G.J. and A.H. Mick, "A Comparison of Electrical Resistance Units for Making a Continuous Measurement of Soil Moisture Under Field Conditions," Plant Physiology, no. 23, pg. 532-543, 1948.

9. Aitchison, G.D., P.F. Butler and C.G. Gurr, "Techniques Associated With the Use of Gypsum Block Soil Moisture Meters," Australian Journal of Applied Sciences, vol. 2, no. 1, pg. 56-75, March, 1951.

10. Slater, C.S. and J.C. Bryant, "Comparison of Four Methods of Soil Moisture Measurements," Soil Science, 61(2), pg. 131-156, 1946.

11. "Report on Water-Saving Devices - Moisture Sensors," Caltrans Inter-departmental Memorandum from E.J. Boll, Associate Landscape Architect, District 07, November 27, 1981.

12. Private communications with Larry Hammond, Dist. 04 Landscape Maintenance Supervisor, Oakland, CA, May - September, 1986.

13. Private communication with Bob Williams, Templeton Maintenance Station, Templeton CA, January 10, 1985.

14. Private communications with Tom Ham, Dist. 11 Senior Landscape Architect, San Diego, CA, January, 1985 through February, 1986.

15. Private communications with Tom Ham, Dist. 11 Senior Landscape Architect, San Diego, CA, November, 1985 through August, 1987.

APPENDIX A

SOIL MOISTURE SENSOR INFORMATION

SOIL MOISTURE BLOCKS

Constructed of stainless steel electrodes encased in a porous gypsum block approximately 1 inch in diameter by 1-1/4 inch long. The Soil Moisture Blocks are designed to have a life expectancy of 3 to 5 years under normal conditions. They give readings of the impedance (resistance and reactance measured in ohms) of the block via a Soil Moisture meter. A scale provided converts the readings into a soil suction equivalence measured in centibars, ranging from field capacity to 300 cb. The buffering action of the gypsum compensates for varying salinity conditions.

The blocks can only be used for soil moisture readings and can not be connected to the irrigation valves or controllers to regulate the amount of water required by the vegetative plantings.

IRROMETER

Operating on the tensiometer principle, the Irrometer consists of a water filled plexiglass tube with a porous ceramic tip, measuring soil suction. As the surrounding soil begins to dry out, water is extracted through the tip creating a partial vacuum inside the tube, which is measured on a gauge. An electrical switch attached to the gauge can be used to automatically override an irrigation valve when a sufficient moisture level is detected.

Two limitations of the use of not only the Irrometer but also other water filled tensiometers is that 1) they are affected by extremes in temperatures (both freezing and extreme heat), and 2) they operate best under moist soil conditions. If the soil in which the sensors are buried is kept relatively dry, as is a majority of Caltrans landscaped areas, the sensitivity of the sensors is reduced and if the water inside the tube is drawn out, the sensor looses its vacuum and requires refilling before becoming functional again.

WATERMASTER

A water filled tensiometer soil moisture indicator, the Watermaster sensor may also be used to automatically override an irrigation valve. The Watermaster's vacuum gauge has a capability of reading from field capacity to 100 cb with greatest accuracy on the low or wet end of the scale. The irrigation switching point can be manually set at any desired level within its reading range. Tube lengths vary so that moisture readings at any depth may be taken.

AQUASCAN

The Aquascan moisture sensor is a complete microprocessor unit, equipped with 16-station controller and 16 sets of sensing probes. At each station or valve, the amount of resistance is measured between the set of buried probes with the information being relayed directly into the microprocessor unit to determine if irrigation is required. The microprocessor has the capability of a fully adjustable range of moisture settings for each set of probes, however, the actual moisture level reading is not obtainable with this unit.

WATERMATIC

Contained in a 1 inch by 2 inch by 4 inch chemically inert porous ceramic block, the Watermatic moisture sensing elements respond to the capillary tension of the water in the soil. As the surrounding soil begins to dry, tension develops. When the preset stress level is reached the sensor switches on allowing irrigation to begin. Three separate preset stress levels are available (5-10, 10-20, and 20-50 Kpa; 1 Kpa = 1 cb), with no means of adjustment. Proper placement of the sensor in the landscaped area and adjustment of the irrigation controller timing should alleviate the lack of adjustment problems.

WATERMARK

The Watermark moisture sensor, is a resistance-type sensor which measures the amount of resistance between two electrodes encapsulated in a 3/4 inch diameter by 2-1/2 inch high porous medium. Readings from the sensors can be directly taken with the use of a meter (passive measurement), or an electronic switching module can be connected to the sensor which is used to automatically override an irrigation valve (active measurement). The electronic module is capable of being set at one of three preset levels (15, 35, or 60 cb). This eliminates some of the problems that may be encountered with having to relocate the sensor if a too wet or too dry situation occurs.

HYDROVISOR

Operating on the same principle as the Irrometer and Water master, the Hydrovisor reacts to the changes in the tension in the soil. The major difference between Hydrovisor and the other tensiometer sensors is that the Hydrovisor's porous ceramic tip is filled with spherical glass beads of a specific size. As the water is extracted from the tip via soil suction, the sensing mechanism switches on allowing for irrigation. Similar to the Watermatic sensors, three preset stress levels (8-12, 20-30, and 40-50 cb) are available with no means of adjustment, but again proper placement and controller timing should alleviate any problems. An override switch is available.

HYDRODYNE

Neither a tensiometer nor an electrical resistance measurer, the Hydrodyne moisture sensing unit was designed to detect the amount of water present in the soil. With 200 tiny "eyes" embedded into the 3/4 inch by 1 inch by 4-1/2 inch Hydrosensor, the percentage of the surrounding soils pore space that is occupied by water is monitored. The sensor is connected to a Hydrodyne unit where the decision making electronics are located. A meter is used to read the fully adjustable upper and lower moisture settings and the existing soil moisture level, read on a scale from 0% (no water) to 100% (total saturation).

MOISTURE MISER

With a similar concept as to that of the Hydrodyne, the Moisture Miser also reads the quantity of water in the soil as opposed to the soil suction or electrical conductivity. The sensor detects the quantity of water in contact with its surface and relays the information to a switching unit which will either allow the irrigation valve to turn on or remain off depending upon the circumstance. Adjustment of the unit is possible, however, a meter is not available to determine where the moisture setting is or what the current moisture reading is.

HYDROMASTER

The Hydromaster moisture sensor works on the principle of measuring the amount of hydrogen ions present in the soil, the more hydrogen ions the wetter the soil, the fewer the ions the drier the soil. An adjustable moisture level control is included which is able to measure from 125 to 2000 milliliters of water per linear cubic (12 by 12 by 6 inches). However, a moisture level meter is not available to either read the current settings or current moisture level in the soil.

APPENDIX B

DATA FROM LABORATORY
PROTOTYPE SYSTEM

PLANT 1

Soil Moisture Blocks (1)

DATE\DEPTH	1-A 8"	1-A 12"	1-A 20"	1-B 8"	1-B 12"	1-B 20"	1-C 8"	1-C 12"	1-C 20"	1-D 8"	1-D 12"	1-D 20"	1-E 8"	1-E 12"	1-E 20"	1-F 8"	1-F 12"	1-F 20"
7-15-85	82	40	9	115	127	98	119	86	200	86	50	48	20	12	86	80	356	260
7-16-85	22	47	9	78	146	138	119	91	230	20	36	29	16	12	82	600	290	25
7-17-85	20	29	9	25	55	127	29	31	240	16	12	27	16	20	40	100	20	20
7-18-85	20	36	0	25	52	135	29	27	250	16	12	25	16	20	36	60	20	20
7-19-85	20	5	5	22	22	75	20	16	240	16	9	20	12	16	29	43	16	16
7-22-85	16	9	9	20	20	50	16	12	185	16	9	12	12	16	22	16	5	16
7-23-85	16	5	9	22	20	66	20	12	177	16	9	9	12	16	22	16	9	16
7-24-85	12	5	5	20	36	169	20	12	181	12	5	12	12	12	24	55	12	16
7-25-85	45	9	5	69	111	280	48	25	196	12	9	25	12	12	22	500	135	42
7-26-85	108	43	0	165	196	350	104	48	210	20	33	30	12	16	25	700	290	240
7-29-85	356	150	0	138	450	1000	290	129	280	158	131	77	20	16	31	230	400	196
7-30-85	450	181	25	108	500	1500	378	150	290	220	185	93	33	16	33	230	400	169
7-31-85	550	210	36	138	550	1500	450	169	312	280	230	104	55	12	36	250	450	250
8-01-85	250	200	48	61	550	1500	378	177	312	22	200	33	20	20	36	80	350	50
8-02-85	89	196	48	42	550	1500	290	177	324	22	181	33	20	12	16	12	290	22
8-05-85	96	173	58	66	260	1500	104	61	356	20	16	60	12	12	27	16	16	22
8-06-85	96	181	61	66	400	1500	98	38	378	22	20	33	12	16	25	12	16	20
8-09-85	270	250	75	138	600	1500	230	89	400	22	29	22	9	12	22	9	20	20
8-12-85	356	290	91	173	700	1500	280	173	450	20	38	75	22	9	29	20	29	91
8-13-85	500	450	98	185	800	1500	356	200	500	27	75	119	5	16	31	20	98	230
8-14-85	290	400	104	158	800	1500	356	192	500	22	66	22	5	16	25	12	12	25
8-15-85	61	378	108	135	800	1500	312	196	550	22	12	16	12	16	20	12	16	20
8-16-85	181	400	115	135	800	1500	312	200	400	25	20	61	9	20	27	16	27	72
8-19-85	600	500	142	230	800	1500	500	250	500	71	142	131	9	20	36	63	290	550
8-20-85	700	550	154	250	800	1500	550	260	500	123	210	142	12	45	38	169	378	700
8-21-85	450	550	150	181	800	1500	500	270	550	22	220	38	9	20	29	20	280	29
8-22-85	135	550	154	146	800	1500	450	270	550	22	162	115	12	16	25	16	16	20
8-23-85	173	500	158	158	800	1500	450	270	550	22	165	131	9	20	29	16	27	119
8-26-85	29	400	165	123	800	1500	196	240	550	22	111	89	9	20	27	12	25	131
8-27-85	25	400	165	119	800	1500	230	250	550	20	65	31	9	16	25	12	25	31
8-28-85	33	378	165	142	800	1500	260	250	600	20	57	50	9	20	27	16	80	220
8-29-85	22	387	165	74	800	1500	270	250	600	22	20	31	9	16	16	12	12	25
8-30-85	20	334	165	71	800	1500	260	250	600	20	20	22	20	16	25	12	20	27
9-03-85	20	185	162	71	800	1500	91	181	600	20	12	25	16	16	58	12	12	12
9-04-85	20	150	154	25	800	1500	84	169	700	22	16	27	20	20	20	16	12	16
9-05-85	20	115	154	27	600	1500	100	165	600	20	16	40	20	20	22	9	16	31
9-06-85	12	9	150	25	20	1500	22	50	600	20	16	50	20	20	22	12	40	177
9-09-85	20	0	9	9	20	700	16	12	550	20	16	27	20	20	20	12	22	33
9-10-85	20	0	9	12	22	378	16	9	378	9	16	25	20	20	20	12	33	20
9-11-85	20	0	9	16	22	312	16	12	312	20	16	33	20	22	20	12	43	42
9-12-85	16	9	12	16	40	312	16	16	270	16	12	38	20	22	20	22	84	154
9-13-85	16	1	9	25	63	334	25	25	260	20	12	43	20	22	20	131	192	280
9-16-85	16	12	5	36	96	450	45	27	270	22	12	45	22	22	16	400	334	378
9-17-85	20	9	1	48	142	450	72	36	280	25	16	50	20	22	20	25	20	20
9-18-85	22	9	0	43	173	450	22	48	260	22	16	25	22	25	20	22	16	12
9-19-85	16	5	5	20	138	378	25	52	240	22	16	31	20	27	22	12	12	16
9-20-85	16	1	5	16	111	450	20	43	220	22	16	31	16	0	22	16	12	16
9-23-85	16	12	5	12	75	334	16	27	220	22	12	33	16	0	22	12	5	12
9-24-85	16	12	5	9	22	290	16	25	220	20	12	36	16	5	22	9	5	12
9-25-85	12	9	5	12	60	280	20	27	210	20	9	40	22	0	22	1	5	5
9-26-85	12	12	1	29	87	280	27	31	200	22	9	45	16	29	22	12	9	9
9-27-85	12	12	1	16	82	280	20	27	200	22	9	36	16	400	20	16	5	9
9-30-85	16	500	1500	55	165	312	66	47	196	29	12	48	20	1000	25	16	12	9
10-01-85	16	378	600	33	162	290	22	47	240	29	12	36	20	600	25	16	9	9
10-02-85	16	450	450	38	165	312	27	48	200	29	12	43	20	1000	29	20	9	9
10-03-85	12	550	1500	47	177	312	40	53	210	47	5	48	20	1500	22	20	9	9
10-04-85	12	700	1500	58	210	334	65	63	220	31	5	52	1	B	27	16	9	5
10-07-85	12	1000	1500	84	230	290	69	75	240	31	9	53	12	"	16	16	9	9
10-08-85	16	800	1500	75	200	280	66	78	250	31	5	42	9	"	16	16	9	9
10-09-85	16	1500	B	66	196	290	40	77	250	31	5	31	22	"	20	16	9	16

B = Broken
(1) All units are centibars

PLANT 1
(1)

Soil Moisture Blocks

	1-A			1-B			1-C			1-D			1-E			1-F		
DATE\DEPTH	8"	12"	20"	8"	12"	20"	8"	12"	20"	8"	12"	20"	8"	12"	20"	8"	12"	20"
10-15-85	20	1500	B	111	220	334	80	87	240	31	9	63	20	B	29	20	12	9
10-21-85	9	1500	"	91	230	280	57	84	220	27	9	40	20	"	550	20	12	12
10-23-85	16	1500	"	68	177	250	22	65	210	27	9	50	20	"	1500	16	9	12
10-25-85	12	1500	"	94	169	230	25	63	177	27	9	20	22	"	1500	20	12	12
10-28-85	12	B	"	91	188	200	55	69	165	31	5	29	22	"	600	16	12	9
10-30-85	16	"	"	75	185	200	42	66	162	27	9	48	22	"	1500	12	12	16
11-01-85	12	"	"	82	192	200	45	68	158	29	13	61	22	"	1500	16	16	12
11-04-85	16	"	"	63	173	192	22	55	150	29	9	40	22	"	B	16	16	16
11-06-85	16	"	"	57	165	192	22	47	146	29	5	50	22	"	"	16	16	16
11-08-85	16	"	"	60	154	192	22	42	131	31	5	61	25	"	"	20	16	16
11-12-85	20	"	"	27	119	185	22	22	108	27	9	40	27	"	"	20	20	20
11-13-85	22	"	"	25	74	181	25	25	93	22	9	58	25	"	"	20	16	20
11-15-85	22	"	"	31	52	150	25	25	77	25	12	61	25	"	"	22	20	20
11-18-85	20	"	"	22	48	82	22	25	66	25	9	60	25	"	"	20	20	20
11-20-85	B	"	"	33	38	69	25	25	65	27	9	63	27	"	"	22	22	22
11-22-85	"	"	"	36	40	58	25	25	61	27	12	69	20	"	"	22	22	20
11-25-85	"	"	"	22	29	31	22	20	53	25	9	45	20	"	"	20	20	20
11-27-85	"	"	"	27	29	20	20	22	47	25	9	60	25	"	"	20	16	20
12-02-85	"	"	"	20	25	22	16	29	38	29	16	66	25	"	"	20	20	22
12-04-85	"	"	"	22	25	25	20	25	31	22	16	66	25	"	"	16	16	20
12-06-85	"	"	"	220	25	25	20	25	27	22	16	68	25	"	"	22	22	22
12-09-85	"	"	"	550	25	22	20	25	22	27	20	77	25	"	"	20	20	22
12-11-85	"	"	"	B	27	25	22	27	22	25	20	91	27	"	"	22	20	22
12-13-85	"	"	"	"	27	25	22	27	22	27	22	87	29	"	"	25	25	25
12-16-85	"	"	"	"	27	25	25	29	25	27	25	91	29	"	"	25	25	25
12-18-85	"	"	"	"	29	25	25	33	25	27	25	93	31	"	"	22	22	25
12-23-85	"	"	"	"	29	25	25	33	25	27	22	96	B	"	"	25	25	25
12-26-85	"	"	"	"	29	25	25	27	25	29	22	98	"	"	"	25	25	25
12-27-85	"	"	"	"	29	25	27	27	27	29	25	98	"	"	"	25	25	25
12-31-85	"	"	"	"	27	25	25	25	25	27	22	12	"	"	"	25	25	22
1-02-86	"	"	"	"	27	22	22	29	22	25	20	60	"	"	"	22	22	22
1-03-86	"	"	"	"	27	22	22	31	22	25	20	65	"	"	"	20	20	22
1-07-86	"	"	"	"	25	20	20	25	20	25	16	63	"	"	"	16	16	22
1-09-86	"	"	"	"	25	20	20	27	20	25	12	60	"	"	"	20	16	22
1-10-86	"	"	"	"	27	22	20	29	20	25	16	60	"	"	"	20	20	25
1-13-86	"	"	"	"	25	22	22	31	22	27	16	66	"	"	"	22	22	22
1-16-86	"	"	"	"	25	22	22	29	22	25	16	68	"	"	"	20	22	22
1-17-86	"	"	"	"	25	22	22	29	20	25	16	66	"	"	"	16	20	20
1-21-86	"	"	"	"	25	22	22	27	20	25	20	65	"	"	"	20	16	22
1-23-86	"	"	"	"	25	20	20	29	20	22	16	65	"	"	"	20	20	20
1-24-86	"	"	"	"	25	20	22	29	20	25	16	68	"	"	"	20	20	20
1-27-86	"	"	"	"	25	22	22	31	20	25	12	68	"	"	"	22	22	20
2-04-86	"	"	"	"	25	20	20	20	16	22	20	63	"	"	"	16	12	20
2-06-86	"	"	"	"	25	20	20	25	20	25	20	66	"	"	"	22	20	22
2-07-86	"	"	"	"	25	20	22	25	20	22	20	65	"	"	"	22	20	25
2-10-86	"	"	"	"	27	22	22	27	20	27	22	71	"	"	"	22	20	25
2-11-86	"	"	"	"	25	20	22	29	22	25	20	68	"	"	"	22	20	25
2-14-86	"	"	"	"	22	20	20	25	20	25	20	75	"	"	"	20	12	22
2-24-86	"	"	"	"	22	20	20	25	20	25	20	75	"	"	"	20	12	22
2-26-86	"	"	"	"	20	16	16	22	16	22	16	72	"	"	"	16	12	16
2-28-86	"	"	"	"	22	20	20	27	20	22	16	74	"	"	"	20	16	20
3-03-86	"	"	"	"	22	16	16	27	16	20	16	77	"	"	"	16	16	16
3-05-86	"	"	"	"	20	16	16	25	16	20	16	75	"	"	"	16	16	16
3-06-86	"	"	"	"	20	12	16	27	12	20	16	78	"	"	"	16	16	16
3-12-86	"	"	"	"	22	20	20	B	16	22	20	119	"	"	"	16	16	22
3-14-86	"	"	"	"	22	16	20	"	16	25	20	123	"	"	"	20	16	22
3-17-86	"	"	"	"	22	20	20	"	16	25	20	100	"	"	"	20	20	22
3-20-86	"	"	"	"	22	16	20	"	16	22	20	104	"	"	"	16	16	20
3-24-86	"	"	"	"	22	16	20	"	16	20	16	123	"	"	"	12	16	16
3-26-86	"	"	"	"	22	16	20	"	16	22	20	123	"	"	"	16	16	16

B = Broken
(1) All units are centibars

PLANT 1
(1)
Soil Moisture Blocks

DATE\DEPTH	1-A 8"	12"	20"	1-B 8"	12"	20"	1-C 8"	12"	20"	1-D 8"	12"	20"	1-E 8"	12"	20"	1-F 8"	12"	20"
3-28-86	B	B	B	B	22	16	20	B	16	20	16	119	B	B	B	16	16	12
3-31-86	"	"	"	"	25	16	22	"	12	20	20	127	"	"	"	12	16	12
4-02-86	"	"	"	"	9	12	22	"	12	20	20	131	"	"	"	16	16	16
4-04-86	"	"	"	"	9	16	20	"	12	20	16	135	"	"	"	16	16	12
4-09-86	"	"	"	"	12	12	20	"	12	20	20	135	"	"	"	16	16	12
4-11-86	"	"	"	"	12	16	20	"	12	20	20	NR	"	"	"	16	16	12
4-14-86	"	"	"	"	12	20	22	"	16	20	20	NR	"	"	"	20	20	16
4-18-86	"	"	"	"	12	20	22	"	16	20	22	12	"	"	"	20	20	16
4-21-86	"	"	"	"	9	20	20	"	12	20	20	119	"	"	"	16	16	12
4-24-86	"	"	"	"	9	16	25	"	12	25	22	111	"	"	"	16	16	16
4-28-86	"	"	"	"	16	1	33	"	12	27	20	108	"	"	"	9	12	12
4-30-86	"	"	"	"	20	22	52	"	12	33	22	111	"	"	"	16	16	9
5-01-86	"	"	"	"	20	20	68	"	12	36	22	115	"	"	"	12	12	5
5-05-86	"	"	"	"	22	22	53	"	16	45	27	131	"	"	"	16	16	9
5-06-86	"	"	"	"	27	25	63	"	12	27	27	138	"	"	"	20	16	9
5-09-86	"	"	"	"	31	27	82	"	12	27	27	135	"	"	"	16	25	9
5-12-86	"	"	"	"	50	40	123	"	12	25	27	111	"	"	"	16	12	5
5-14-86	"	"	"	"	58	48	158	"	12	22	25	104	"	"	"	16	5	5
5-19-86	"	"	"	"	71	75	165	"	16	20	25	115	"	"	"	20	12	9
5-23-86	"	"	"	"	84	98	177	"	20	22	27	98	"	"	"	22	12	1
5-27-86	"	"	"	"	98	115	196	"	20	22	29	115	"	"	"	12	12	1
6-02-86	"	"	"	"	138	165	230	"	36	40	58	142	"	"	"	16	B	1
6-04-86	"	"	"	"	154	181	270	"	40	75	61	146	"	"	"	27	"	9
6-09-86	"	"	"	"	173	220	280	"	53	55	111	154	"	"	"	80	"	71

B = Broken
(1) All units are centibars.

PLANT NUMBER 2 (1)

	Soil Moisture Blocks			Irrometer	Watermatic (2)
DATE\DEPTH	8"	12"	20"	11"	9"
7-15-85	12	16	12	30	15
7-16-85	12	16	12	28	"
7-17-85	16	16	12	1	"
7-18-85	16	12	9	2	"
7-19-85	12	12	9	0	"
7-22-85	16	9	9	4	"
7-23-85	9	9	9	5	"
7-24-85	9	12	9	5	"
7-25-85	9	9	9	6	"
7-26-85	9	9	9	0	"
7-29-85	9	9	9	2	"
7-30-85	12	12	12	1	"
7-31-85	12	16	20	6	"
8-01-85	27	22	9	12	"
8-02-85	9	12	43		"
8-05-85	12	48	50	24	"
8-06-85	16	52	57	11	"
8-09-85	12	47	55	9	"
8-12-85	16	16	38	0	"
8-13-85	20	22	48	14	"
8-14-85	6	22	45	0	"
8-15-85	16	16	45	0	"
8-16-85	12	22	22	0	"
8-19-85	16	12	20	0	"
8-20-85	16	12	16	2	"
8-21-85	12	12	20	2	"
8-22-85	12	16	27	0	"
8-23-85	12	21	29	0	"
8-26-85	12	12	20	2	"
8-27-85	12	16	20	0	"
8-28-85	22	22	12	0	"
8-29-85	12	45	48	24	"
8-30-85	12	50	40	10	"
9-03-85	12	123	78	68	"
9-04-85	12	138	91	75	"
9-05-85	16	142	100	30	"
9-06-85	16	58	45	64	"
9-09-85	20	71	142	88	"
9-10-85	16	71	154	72	"
9-11-85	20	89	162	80	"
9-12-85	20	93	162	50	"
9-13-85	25	119	169	70	"
9-16-85	22	138	177	50	"
9-17-85	50	154	181	70	"
9-18-85	40	158	185	78	"
9-19-85	36	131	188	80	"
9-20-85	45	135	188	70	"
9-23-85	53	150	196	82	"
9-24-85	61	150	196	82	"
9-25-85	65	162	196	90	"
9-26-85	22	1	185	4	"
9-27-85	25	20	169	15	"
9-30-85	24	12	100	2	"
10-01-85	24	12	91	5	"
10-02-85	22	12	93	2	"

B = Broken
(1) All units are centibars.
(2) Preset, nonadjustable 15 cb. sensor.

PLANT NUMBER 2 (1)

	Soil Moisture Blocks			Irrometer	Watermatic (2)
DATE\DEPTH	8"	12"	20"	11"	9"
10-03-85	33	29	98	18	15
10-04-85	42	52	108	28	"
10-07-85	27	36	146	4	"
10-08-85	48	47	154	12	"
10-09-85	47	57	165	13	"
10-15-85	60	38	198	8	"
10-21-85	25	71	240	0	"
10-23-85	25	50	240	8	"
10-25-85	29	57	230	50	"
10-28-85	31	66	220	80	"
10-30-85	33	71	220	65	"
11-01-85	43	78	220	80	"
11-04-85	27	40	220	4	"
11-06-85	29	47	200	24	"
11-08-85	29	55	196	33	"
11-12-85	B	20	210	0	"
11-13-85	"	22	188	0	"
11-15-85	"	22	169	2	"
11-18-85	"	20	142	0	"
11-20-85	"	22	135	0	"
11-22-85	"	16	123	0	"
11-25-85	"	22	91	0	"
11-27-85	"	22	65	2	"
12-02-85	"	20	36	0	"
12-04-85	"	20	25	0	"
12-06-85	"	20	25	0	"
12-09-85	"	20	25	0	"
12-11-85	"	22	25	0	"
12-13-85	"	25	27	0	"
12-16-85	"	25	27	2	"
12-18-85	"	25	27	2	"
12-23-85	"	22	25	8	"
12-26-85	"	25	27	8	"
12-27-85	"	27	27	9	"
12-31-85	"	22	25	0	"
1-02-86	"	22	25	0	"
1-03-86	"	20	22	0	"
1-07-86	"	16	22	0	"
1-09-86	"	20	22	3	"
1-10-86	"	20	22	3	"
1-13-86	"	20	25	5	"
1-16-86	"	20	25	0	"
1-17-86	"	16	22	0	"
1-21-86	"	12	22	0	"
1-23-86	"	5	22	0	"
1-24-86	"	5	20	0	"
1-27-86	"	12	12	5	"
2-04-86	"	16	22	0	"
2-06-86	"	20	22	5	"
2-07-86	"	16	22	6	"
2-10-86	"	12	22	12	"
2-11-86	"	16	25	13	"
2-14-86	"	17	26	13	"
2-24-86	"	9	22	0	"
2-26-86	"	9	22	12	"

B = Broken
(1) All units are centibars.
(2) Preset, nonadjustable 15 cb. sensor.

PLANT NUMBER 2 (1)

DATE\DEPTH	Soil Moisture Blocks 8"	12"	20"	Irrometer 11"	Watermatic (2) 9"
2-28-86	B	5	20	16	15
3-03-86	"	9	22	25	"
3-05-86	"	12	20	30	"
3-06-86	"	9	20	50	"
3-12-86	"	16	22	6	"
3-14-86	"	20	22	5	"
3-17-86	"	20	25	0	"
3-20-86	"	16	22	10	"
3-24-86	"	B	22	33	"
3-26-86	"	"	20	46	"
3-28-86	"	"	20	50	"
3-31-86	"	"	20	62	"
4-02-86	"	"	22	60	"
4-04-86	"	"	22	70	"
4-09-86	"	"	27	0	"
4-11-86	"	"	25	18	"
4-14-86	"	"	25	38	"
4-18-86	"	"	27	56	"
4-21-86	"	"	27	65	"
4-24-86	"	"	27	72	"
4-28-86	"	"	27	80	"
4-30-86	"	"	29	82	"
5-01-86	"	"	27	84	"
5-05-86	"	"	27	72	"
5-06-86	"	"	29	70	"
5-09-86	"	"	31	80	"
5-12-86	"	"	31	89	"
5-14-86	"	"	31	76	"
5-19-86	"	"	33	90	"
5-23-86	"	"	38	46	"
5-27-86	"	"	36	50	"
6-02-86	"	"	43	25	"
6-04-86	"	"	47	15	"
6-09-86	"	"	50	15	"
6-11-86	"	"	52	60	"
6-13-86	"	"	63	70	"
6-18-86	"	"	69	70	"
6-20-86	"	"	71	8	"
6-23-86	"	"	31	4	"
6-26-86	"	"	29	0	"
7-01-86	"	"	33	12	"
7-07-86	"	"	312	11	"
7-09-86	"	"	280	3	"
7-10-86	"	"	312	5	"

B = Broken
(1) All units are centibars.
(2) Preset, nonadjustable 15 cb. sensor.

PLANT NUMBER 3 (1)

DATE\DEPTH	Soil Moisture Blocks 8"	Soil Moisture Blocks 12"	Soil Moisture Blocks 20"	Irrometer 11"	Irrometer 14"	Hydrovisor (2) 10"
7-15-85	60	20	12	54	60	20-30
7-16-85	74	29	16	60	67	"
7-17-85	78	38	20	62	70	"
7-18-85	87	43	20	67	78	"
7-19-85	96	48	22	68	76	"
7-22-85	119	60	27	70	75	"
7-23-85	123	63	31	71	79	"
7-24-85	138	66	29	23	70	"
7-25-85	142	69	29	22	76	"
7-26-85	138	69	36	54	78	"
7-29-85	150	78	43	70	76	"
7-30-85	56	12	16	72	8	"
7-31-85	48	22	20	13	14	"
8-01-85	57	29	22	21	24	"
8-02-85	65	36	25	52	42	"
8-05-85	89	58	50	70	73	"
8-06-85	100	63	42	71	75	"
8-09-85	135	74	45	74	79	"
8-12-85	29	0	20	70	13	Relocated 7"
8-13-85	27	0	22	60	15	"
8-14-85	27	0	20	68	22	"
8-15-85	40	16	27	70	35	"
8-16-85	29	40	16	70	40	"
8-19-85	57	50	29	50	53	"
8-20-85	65	53	33	56	69	"
8-21-85	36	47	36	27	16	"
8-22-85	53	52	36	40	40	"
8-23-85	66	57	38	51	68	"
8-26-85	29	33	16	18	25	"
8-27-85	43	33	12	34	52	"
8-28-85	58	40	20	45	72	"
8-29-85	69	48	20	53	78	"
8-30-85	80	55	22	58	80	"
9-03-85	80	65	36	50	74	"
9-04-85	74	63	40	45	8	"
9-05-85	77	66	43	46	26	"
9-06-85	82	69	43	49	51	"
9-09-85	104	80	50	58	75	"
9-10-85	1500	75	53	58	64	"
9-11-85	800	31	47	60	30	"
9-12-85	50	38	43	0	7	"
9-13-85	1000	36	42	8	20	"
9-16-85	1500	48	47	38	60	"
9-17-85	1500	57	47	42	66	"
9-18-85	1500	33	16	0	0	"
9-19-85	1500	33	20	0	0	"
9-20-85	1500	36	20	0	7	"
9-23-85	1500	33	16	28	32	"
9-24-85	B	31	12	35	46	"
9-25-85	"	33	20	44	66	"
9-26-85	"	36	12	0	2	"
9-27-85	"	27	12	0	2	"
9-30-85	"	33	20	22	24	"
10-01-85	"	29	16	35	37	"
10-02-85	"	31	20	45	49	"
10-03-85	"	36	20	0	2	"
10-04-85	"	9	20	0	0	"
10-07-85	"	31	20	24	25	"
10-08-85	"	31	20	42	40	"
10-09-85	"	33	20	57	53	"

B = Broken
(1) All units are centibars.
(2) Preset, nonadjustable 20-30 cb. sensor.

PLANT NUMBER 3
(1)

	Soil Moisture Blocks			Irrometer		Hydrovisor (2)
DATE\DEPTH	8"	12"	20"	11"	14"	10"
10-15-85	B	33	22	22	23	20-30
10-21-85	"	36	22	0	0	"
10-23-85	"	31	22	0	4	"
10-25-85	"	33	22	6	10	"
10-28-85	"	31	22	48	36	"
10-30-85	"	33	27	64	54	"
11-01-85	"	36	22	0	0	"
11-04-85	"	5	22	10	12	"
11-06-85	"	9	22	46	38	"
11-08-85	"	22	25	64	56	"
11-12-85	"	27	25	0	0	"
11-13-85	"	20	25	0	0	"
11-15-85	"	20	25	0	2	"
11-18-85	"	16	25	0	4	"
11-20-85	"	16	25	2	6	"
11-22-85	"	16	27	9	12	"
11-25-85	"	25	25	0	0	"
11-27-85	"	20	25	0	0	"
12-02-85	"	16	25	0	0	"
12-04-85	"	16	25	0	0	"
12-06-85	"	20	25	0	0	"
12-09-85	"	22	25	0	0	"
12-11-85	"	25	27	0	0	"
12-13-85	"	25	27	0	0	"
12-16-85	"	27	27	0	4	"
12-18-85	"	27	27	0	4	"
12-23-85	"	25	27	0	5	"
12-26-85	"	27	29	2	8	"
12-27-85	"	27	29	2	8	"
12-31-85	"	22	27	0	0	"
1-02-86	"	22	27	0	0	"
1-03-86	"	20	25	0	0	"
1-07-86	"	20	25	0	0	"
1-09-86	"	22	25	0	1	"
1-10-86	"	22	25	0	1	"
1-13-86	"	25	25	0	4	"
1-16-86	"	22	27	0	0	"
1-17-86	"	16	22	0	0	"
1-21-86	"	20	22	0	0	"
1-23-86	"	22	25	0	2	"
1-24-86	"	22	25	0	2	"
1-27-86	"	22	25	0	2	"
2-04-86	"	20	25	0	0	"
2-06-86	"	25	25	0	0	"
2-07-86	"	25	25	0	0	"
2-10-86	"	25	25	2	5	"
2-11-86	"	25	27	8	8	"
2-14-86	"	25	25	7	6	"
2-24-86	"	22	22	0	0	"
2-26-86	"	22	22	14	8	"
2-28-86	"	22	22	36	12	"
3-03-86	"	22	22	62	24	"
3-05-86	"	22	22	75	26	"
3-06-86	"	20	20	80	15	"
3-12-86	"	22	22	0	0	"
3-14-86	"	25	25	0	0	"
3-17-86	"	27	25	0	0	"
3-20-86	"	27	25	5	7	"
3-24-86	"	25	22	74	25	"
3-26-86	"	25	22	80	34	"

B = Broken
(1) All units are centibars.
(2) Preset, nonadjustable 20-30 cb. sensor.

PLANT NUMBER 3 (1)

	Soil Moisture Blocks			Irrometer		Hydrovisor (2)
DATE\DEPTH	8"	12"	20"	11"	14"	10"
3-28-86	B	25	22	2	7	20-30
4-02-86	"	27	22	78	46	"
4-04-86	"	27	22	78	12	"
4-09-86	"	27	22	0	0	"
4-11-86	"	25	22	34	24	"
4-14-86	"	25	22	70	42	"
4-18-86	"	25	20	76	43	"
4-21-86	"	22	20	85	46	"
4-24-86	"	25	22	82	53	"
4-28-86	"	25	20	85	66	"
4-30-86	"	22	20	85	65	"
5-01-86	"	22	22	85	65	"
5-05-86	"	20	22	83	42	"
5-06-86	"	25	22	82	56	"
5-09-86	"	16	20	82	32	"
5-12-86	"	16	20	82	4	"
5-14-86	"	16	20	26	26	"
5-19-86	"	20	20	60	60	"
5-23-86	"	20	20	52	57	"
5-27-86	"	16	20	16	20	"
6-02-86	"	22	20	67	61	"
6-04-86	"	20	20	0	0	"
6-09-86	"	22	22	0	2	
6-11-86	"	27	20	69	68	"
6-13-86	"	38	B	70	68	"
6-18-86	"	36	"	85	68	"
6-20-86	"	25	"	0	4	"
6-23-86	"	29	"	70	15	
6-26-86	"	27	"	80	38	"
7-01-86	"	47	"	77	55	"
7-07-86	"	48	"	54	40	"
7-09-86	"	68	"	35	33	"
7-10-86	"	29	"	2	5	"

B = Broken
(1) All units are centibars.
(2) Preset, nonadjustable 20-30 cb. sensor.

PLANT NUMBER 4
(1)

DATE\DEPTH	Soil Moisture Blocks 8"	12"	20"	Irrometer 14"	Watermark 10"	14"	20"
7-15-85	31	25	22	28	2		50
7-16-85	27	20	22	21	0		50
7-17-85	20	20	20	18	0		49
7-18-85	48	47	29	38	13		52
7-19-85	42	20	25	25	10		58
7-22-85	43	22	27	28	0		62
7-23-85	22	20	22	22	0		57
7-24-85	22	16	16	26	0		62
7-25-85	69	68	55	62	23		62
7-26-85	47	20	45	39	2		62
7-29-85	104	142	100	80	8		65
7-30-85	29	22	58	48	2		65
7-31-85	40	25	22	42	2		65
8-01-85	75	80	84	78	23		70
8-02-85	57	78	77	70	2		70
8-05-85	131	181	169	78	8		73
8-06-85	77	115	162	80	1		70
8-09-85	177	312	312	85	8		75
8-12-85	154	230	334	85	8		85
8-13-85	250	312	450	85	49		85
8-14-85	158	240	356	88	8		87
8-15-85	260	378	550	88	49		87
8-16-85	104	185	290	81	2		87
8-19-85	123	240	334	88	8		00
8-20-85	33	135	240	76	2		00
8-21-85	27	80	154	174	2		00
8-22-85	89	188	200	80	(2)		105
8-23-85	181	312	324	88	"		105
8-26-85	290	400	600	88	"		110
8-27-85	173	356	450	86	"		115
8-28-85	334	450	600	88	"		121
8-29-85	230	400	550	80	"		136
8-30-85	378	500	700	88	"		136
9-03-85	500	700	800	88	"		182
9-04-85	334	600	700	65	"		190
9-05-85	400	700	800	75	"		200
9-06-85	71	169	378	78	"		200
9-09-85	131	230	312	80	"		200
9-10-85	185	280	334	70	"		200
9-11-85	240	334	378	78	"		200
9-12-85	108	185	185	78	"		200
9-13-85	154	220	196	80	"		200
9-16-85	192	312	240	80	"		B
9-17-85	69	196	188	47	"		"
9-18-85	71	200	108	52	"		"
9-19-85	68	119	68	56	"		"
9-20-85	93	138	80	62	"		"
9-23-85	146	181	84	66	"		"
9-24-85	200	220	123	70	"		"
9-25-85	260	260	169	78	"		"
9-26-85	177	210	150	64	"		"
9-27-85	270	260	181	74	"		"
9-30-85	82	135	119	55	"		"
10-01-85	111	135	115	63	"		"
10-02-85	173	173	142	68	"		"
10-03-85	230	220	177	72	"		"
10-04-85	27	123	98	70	"		"
10-07-85	200	165	173	75	"		"
10-08-85	260	181	210	76	"		"
10-09-85	220	150	220	76	"		"

B = Broken
(1) All units are centibars.
(2) Sensor connected to electronic module at 35 cb. level.

PLANT NUMBER 4
(1)

DATE\DEPTH	Soil Moisture Blocks 8"	12"	20"	Irrometer 14"	Watermark 10"	14"	20"
10-15-85	220	165	280	80	(2)		B
10-21-85	25	104	181	80	"		"
10-23-85	31	68	84	46	"		"
10-25-85	74	71	98	58	"		"
10-28-85	150	84	96	68	"		"
10-30-85	142	78	72	58	"		"
11-01-85	177	96	29	65	"	197	"
11-04-85	200	98	31	60	"	87	"
11-06-85	230	115	29	55	"	87	"
11-08-85	260	131	25	47	"	44	"
11-12-85	29	22	25	0	"	2	"
11-13-85	27	22	20	8	"	18	"
11-15-85	29	22	25	8	"	28	"
11-18-85	29	22	25	6	"	28	"
11-20-85	36	27	25	2	"	18	"
11-22-85	36	25	25	12	"	28	"
11-25-85	25	27	22	0	"	2	"
11-27-85	27	27	22	2	"	2	"
12-02-85	22	25	20	0	"	1	"
12-04-85	20	22	20	0	"	2	"
12-06-85	20	22	20	0	"	1	"
12-09-85	22	22	22	0	"	2	"
12-11-85	25	25	25	7	"	8	"
12-13-85	25	25	25	8	"	13	"
12-16-85	25	25	27	10	"	18	"
12-18-85	25	25	25	10	"	23	"
12-23-85	25	25	25	15	"	28	"
12-26-85	29	27	27	15	"	31	"
12-27-85	29	27	27	16	"	31	"
12-31-85	20	25	25	2	"	2	"
1-02-86	20	22	25	8	"	2	"
1-03-86	20	20	22	8	"	5	"
1-07-86	20	20	20	0	"	2	"
1-09-86	20	20	20	8	"	2	"
1-10-86	20	20	20	8	"	2	"
1-13-86	20	16	22	10	"	11	"
1-16-86	16	20	20	2	"	2	"
1-17-86	12	16	16	2	"	2	"
1-21-86	16	16	20	9	"	2	"
1-23-86	16	16	20	5	"	5	"
1-24-86	16	16	22	10	"	5	"
1-27-86	16	16	22	10	"	13	"
2-04-86	16	20	20	7	"	2	"
2-06-86	16	20	20	8	"	2	"
2-07-86	16	16	20	10	"	2	"
2-10-86	16	16	22	15	"	18	"
2-11-86	16	16	22	8	"	8	"
2-14-86	16	20	20	8	"	8	"
2-24-86	12	12	16	10	"	2	"
2-26-86	12	9	16	16	"	13	"
2-28-86	16	9	16	16	"	18	"
3-03-86	20	9	16	15	"	18	"
3-05-86	9	5	12	12	"	8	"
3-06-86	16	9	16	4	"	23	"
3-12-86	16	16	16	4	"	1	"
3-14-86	16	20	16	7	"	1	"
3-17-86	20	20	20	5	"	1	"
3-20-86	16	12	16	13	"	13	"
3-24-86	12	5	16	14	"	23	"
3-26-86	20	5	16	15	"	23	"

B = Broken
(1) All units are centibars.
(2) Sensor connected to electronic module at 35 cb. level.

PLANT NUMBER 4
(1)

DATE\DEPTH	Soil Moisture Blocks 8"	12"	20"	Irrometer 14"	Watermark 10"	14"	20"
3-28-86	9	5	12	8	(2)	12	B
3-31-86	12	9	22	12	"	8	"
4-02-86	20	5	16	14	"	34	"
4-04-86	16	5	16	14	"	22	"
4-09-86	12	12	16	10	"	2	"
4-11-86	16	5	16	18	"	22	"
4-14-86	20	5	16	16	"	28	"
4-18-86	20	9	16	18	"	25	"
4-21-86	16	5	12	16	"	23	"
4-24-86	20	5	12	17	"	34	"
4-28-86	45	5	12	23	"	44	"
4-30-86	27	5	9	17	"	34	"
5-01-86	43	9	9	23	"	49	"
5-05-86	27	5	9	10	"	25	"
5-06-86	31	5	1	20	"	44	"
5-09-86	38	9	0	26	"	39	"
5-12-86	31	9	0	30	"	41	"
5-14-86	27	12	0	22	"	34	"
5-19-86	22	20	1	14	"	15	"
5-23-86	22	42	5	7	"	15	"
5-27-86	24	43	5	27	"	44	"
6-02-86	53	43	5	27	"	44	"
6-04-86	20	50	9	18	"	57	"
6-09-86	B	78	12	26	"	110	"
6-11-86	"	127	104	30	"	65	"
6-13-86	"	128	104	35	"	65	"
6-18-86	"	165	100	45	"	85	"
6-20-86	"	196	82	55	"	103	"
6-23-86	"	230	181	70	"	103	"
6-26-86	"	270	135	64	"	127	"
7-01-86	"	260	131	B	"	117	"
7-07-86	"	378	334	"	"	200	"
7-09-86	"	290	356	"	"	200	"

B = Broken
(1) All units are centibars.
(2) Sensor connected to electronic module at 35 cb. level.

PLANT NUMBER 5
(1)

	Soil Moisture Blocks			Watermark
DATE\DEPTH	8"	12"	20"	10"
7-15-85	89	450	500	85
7-16-85	185	550	500	145
7-17-85	250	600	378	182
7-18-85	312	700	550	200
7-19-85	356	700	550	200
7-22-85	68	600	700	18
7-23-85	131	600	450	39
7-24-85	200	700	500	80
7-25-85	334	800	500	166
7-26-85	450	800	500	200
7-29-85	290	600	550	65
7-30-85	378	700	1500	105
7-31-85	400	700	356	145
8-01-85	450	700	550	189
8-02-85	400	600	550	87
8-05-85	450	700	400	117
8-06-85	500	700	400	155
8-09-85	550	700	450	160
8-12-85	700	800	1000	200
8-13-85	700	800	600	200
8-14-85	700	700	700	200
8-15-85	8	800	700	18
8-16-85	8	700	800	2
8-19-85	16	450	400	8
8-20-85	16	400	600	8
8-21-85	12	378	550	13
8-22-85	16	400	800	23
8-23-85	16	400	550	23
8-26-85	12	500	450	39
8-27-85	16	550	450	39
8-28-85	20	550	400	18
8-29-85	20	550	800	34
8-30-85	20	550	550	39
9-03-85	27	600	700	70
9-04-85	40	600	550	80
9-05-85	61	600	550	100
9-06-85	115	600	800	126
9-09-85	22	74	600	105
9-10-85	22	74	550	2
9-11-85	8	69	550	2
9-12-85	20	72	600	8
9-13-85	20	53	550	0
9-16-85	16	60	800	0
9-17-85	16	60	550	2
9-18-85	12	60	550	2
9-19-85	4	55	500	2
9-20-85	8	50	500	0
9-23-85	0	38	500	0
9-24-85	0	38	B	0
9-25-85	0	31	"	0
9-26-85	0	20	"	18
9-27-85	0	16	"	8
9-30-85	22	40	"	44
10-01-85	20	80	"	62
10-02-85	45	20	"	73
10-03-85	47	22	"	95
10-04-85	50	22	"	95
10-07-85	400	38	"	200
10-08-85	450	42	"	200
10-09-85	500	40	"	200

B = Broken
(1) All units are centibars.

PLANT NUMBER 5
(1)

	Soil Moisture Blocks			Watermark
DATE\DEPTH	8"	12"	20"	10"
10-15-85	600	38	B	200
10-21-85	550	36	"	200
10-23-85	400	25	"	200
10-25-85	290	25	"	200
10-28-85	290	25	"	174
10-30-85	75	22	"	18
11-01-85	16	20	"	11
11-04-85	20	25	"	34
11-06-85	5	25	"	13
11-08-85	1	25	"	8
11-12-85	12	20	"	2
11-13-85	9	22	"	2
11-15-85	9	22	"	2
11-18-85	5	20	"	8
11-20-85	9	22	"	8
11-22-85	5	20	"	8
11-25-85	9	20	"	2
11-27-85	9	22	"	2
12-02-85	5	16	"	1
12-04-85	5	12	"	2
12-06-85	16	12	"	1
12-09-85	5	16	"	1
12-11-85	5	16	"	2
12-13-85	5	16	"	5
12-16-85	5	20	"	8
12-18-85	29	20	"	8
12-23-85	9	22	"	23
12-26-85	12	25	"	23
12-27-85	16	25	"	25
12-31-85	9	22	"	2
1-02-86	9	22	"	2
1-03-86	5	20	"	2
1-07-86	5	16	"	2
1-09-86	5	12	"	2
1-10-86	5	16	"	2
1-13-86	9	16	"	5
1-16-86	9	16	"	2
1-17-86	9	9	"	2
1-21-86	5	12	"	2
1-23-86	2	2	"	2
1-24-86	9	12	"	2
1-27-86	5	12	"	8
2-04-86	9	12	"	2
2-06-86	16	12	"	2
2-07-86	22	12	"	2
2-10-86	9	12	"	2
2-11-86	12	12	"	8
2-14-86	12	12	"	8
2-24-86	5	9	"	2
2-26-86	5	9	"	2
2-28-86	5	9	"	0
3-03-86	9	9	"	13
3-05-86	9	9	"	8
3-06-86	5	5	"	18
3-12-86	12	12	"	1
3-14-86	5	16	"	1
3-17-86	20	20	"	1
3-20-86	5	16	"	5
3-24-86	9	9	"	18
3-26-86	12	9	"	23

B = Broken
(1) All units are centibars.

PLANT NUMBER 5
(1)

	Soil Moisture Blocks			Watermark
DATE\DEPTH	8"	12"	20"	10"
3-31-86	B	9	B	28
4-02-86	"	9	"	36
4-04-86	"	9	"	28
4-09-86	"	9	"	2
4-11-86	"	9	"	2
4-14-86	"	9	"	8
4-18-86	"	9	"	8
4-21-86	"	9	"	18
4-24-86	"	5	"	25
4-28-86	"	9	"	34
4-30-86	"	9	"	50
5-01-86	"	12	"	62
5-05-86	"	9	"	13
5-06-86	"	9	"	31
5-09-86	"	9	"	34
5-12-86	"	9	"	28
5-14-86	"	9	"	39
5-19-86	"	29	"	64
5-23-86	"	29	"	64
5-27-86	"	91	"	70
6-02-86	"	158	"	178
6-04-86	"	165	"	190
6-09-86	"	192	"	65
6-11-86	"	250	"	75
6-13-86	"	312	"	64
6-18-86	"	356	"	84
6-20-86	"	400	"	110
6-23-86	"	400	"	25
6-26-86	"	450	"	28
7-01-86	"	450	"	31
7-07-86	"	B	"	200
7-09-86	"	"	"	174

B = Broken
(1) All units are centibars.

PLANT NUMBER 6
(1)

DATE\DEPTH	Soil Moisture Blocks 3"	Soil Moisture Blocks 3"	Watermaster 3"	Watermaster 5"	Watermatic (2) 3"
7-15-85	27	27	0	0	15
7-16-85	27	27	0	0	"
7-17-85	25	27	0	0	"
7-18-85	27	27	0	0	"
7-19-85	27	27	0	0	"
7-22-85	25	25	0	0	"
7-23-85	25	65	35	10	"
7-24-85	43	84	42	17	"
7-25-85	61	100	60	21	"
7-26-85	60	72	52	24	"
7-29-85	84	150	B	41	"
7-30-85	53	71	"	36	"
7-31-85	82	115	"	45	"
8-01-85	104	146	"	56	"
8-02-85	123	162	"	75	"
8-05-85	177	200	"	75	"
8-06-85	96	154	"	75	"
8-09-85	196	240	"	90	"
8-12-85	280	356	"	80	"
8-13-85	60	63	"	65	"
8-14-85	100	135	"	70	"
8-15-85	68	77	"	78	"
8-16-85	55	57	"	80	"
8-19-85	181	210	"	88	"
8-20-85	220	220	"	100	"
8-21-85	66	36	"	B	"
8-22-85	111	87	"	"	"
8-23-85	135	169	"	"	"
8-26-85	240	240	"	"	"
8-27-85	450	270	"	"	"
8-28-85	312	150	"	"	"
8-29-85	312	181	"	"	"
8-30-85	334	230	"	"	"
9-03-85	290	290	"	"	"
9-04-85	146	58	"	"	"
9-05-85	165	111	"	"	"
9-06-85	250	192	"	"	"
9-09-85	356	270	"	"	"
9-10-85	27	22	"	"	"
9-11-85	25	20	"	"	"
9-12-85	25	25	"	"	"
9-13-85	27	50	"	"	"
9-16-85	66	20	"	"	"
9-17-85	52	22	"	"	"
9-18-85	20	22	"	"	"
9-19-85	25	20	"	"	"
9-20-85	25	20	"	"	"
9-23-85	22	20	"	"	"
9-24-85	22	20	"	"	"
9-25-85	25	20	"	"	"
9-26-85	22	20	"	"	"
9-27-85	22	22	"	"	"
9-30-85	27	25	"	"	"
10-01-85	22	20	"	"	"
10-02-85	22	20	"	"	"
10-03-85	22	22	"	"	"
10-04-85	22	22	"	"	"
10-07-85	25	25	"	"	"
10-08-85	22	27	"	"	"
10-09-85	25	57	"	"	"

B = Broken
(1) All units are centibars.
(2) Preset, nonadjustable 15 cb. sensor.

PLANT NUMBER 6 (1)

DATE\DEPTH	Soil Moisture Blocks 3"	3"	Watermaster 3"	5"	Watermatic (2) 3"
10-15-85	25	43	B	B	15
10-21-85	25	27	"	"	"
10-23-85	22	27	"	"	"
10-25-85	22	27	"	"	"
10-28-85	22	25	"	"	"
10-30-85	22	25	"	"	"
11-01-85	25	27	"	"	"
11-04-85	22	29	"	"	"
11-06-85	25	29	"	"	"
11-08-85	22	25	"	"	"
11-12-85	27	29	"	"	"
11-13-85	27	27	"	"	"
11-15-85	27	29	"	"	"
11-18-85	27	27	"	"	"
11-20-85	27	29	"	"	"
11-22-85	27	27	"	"	"
11-25-85	25	25	"	"	"
11-27-85	25	25	"	"	"
12-02-85	22	22	"	"	"
12-04-85	22	22	"	"	"
12-06-85	22	22	"	"	"
12-09-85	27	27	"	"	"
12-11-85	29	29	"	"	"
12-13-85	29	29	"	"	"
12-16-85	29	29	"	"	"
12-18-85	29	29	"	"	"
12-23-85	29	29	"	"	"
12-26-85	29	29	"	"	"
12-27-85	29	31	"	"	"
12-31-85	25	25	"	"	"
1-02-86	25	25	"	"	"
1-03-86	22	22	"	"	"
1-07-86	25	25	"	"	"
1-09-86	25	25	"	"	"
1-10-86	25	25	"	"	"
1-13-86	27	27	"	"	"
1-16-86	25	25	"	"	"
1-17-86	22	22	"	"	"
1-21-86	25	22	"	"	"
1-23-86	22	22	"	"	"
1-24-86	25	25	"	"	"
1-27-86	27	27	"	"	"
2-04-86	22	22	"	"	"
2-06-86	27	27	"	"	"
2-07-86	27	27	"	"	"
2-10-86	29	29	"	"	"
2-11-86	27	27	"	"	"
2-14-86	27	27	"	"	"
2-24-86	20	20	"	"	"
2-26-86	20	20	"	"	"
2-28-86	20	20	"	"	"
3-03-86	22	25	"	"	"
3-05-86	22	25	"	"	"
3-06-86	20	22	"	"	"
3-12-86	22	20	"	"	"
3-14-86	22	22	"	"	"
3-17-86	22	22	"	"	"
3-20-86	22	22	"	"	"
3-24-86	16	43	"	"	"
3-26-86	22	68	"	"	"

B = Broken
(1) All units are centibars.
(2) Preset, nonadjustable 15 cb. sensor.

PLANT NUMBER 6 (1)

	Soil Moisture Blocks		Watermaster		Watermatic (2)
DATE\DEPTH	3"	3"	3"	5"	3"
3-28-86	20	87	B	B	15
3-31-86	22	108	"	"	"
4-02-86	22	127	"	"	"
4-04-86	25	57	"	"	"
4-09-86	22	25	"	"	"
4-11-86	20	31	"	"	"
4-14-86	22	45	"	"	"
4-18-86	22	25	"	"	"
4-21-86	22	43	"	"	"
4-24-86	25	115	"	"	"
4-28-86	27	108	"	"	"
4-30-86	25	78	"	"	"
5-01-86	25	31	"	"	"
5-05-86	22	22	"	"	"
5-06-86	25	27	"	"	"
5-09-86	25	29	"	"	"
5-12-86	22	63	"	"	"
5-14-86	27	142	"	"	"
5-19-86	29	260	"	"	"
5-23-86	33	378	"	"	"
5-27-86	119	400	"	"	"
6-02-86	135	400	"	"	"
6-04-86	119	400	"	"	"
6-09-86	150	181	"	"	"
6-11-86	66	158	"	"	"
6-13-86	150	181	"	"	"
6-18-86	123	33	"	"	"
6-20-86	188	146	"	"	"
6-23-86	270	260	"	"	"
6-26-86	220	230	"	"	"
7-01-86	192	29	"	"	"
7-07-86	78	16	"	"	"
7-09-86	146	16	"	"	"

B = Broken
(1) All units are centibars.
(2) Preset, nonadjustable 15 cb. sensor.

PLANT NUMBER 7
(1)

DATE\DEPTH	Soil Moisture Blocks 3"	Soil Moisture Blocks 3"	Watermaster 3"	Hydrovisor (2) 4"
7-15-85	98	127	57	20-30
7-16-85	111	162	67	"
7-17-85	111	52	14	"
7-18-85	22	22	0	"
7-19-85	33	25	29	"
7-22-85	69	138	68	"
7-23-85	84	181	49	"
7-24-85	96	181	50	"
7-25-85	119	196	55	"
7-26-85	135	192	70	"
7-29-85	150	181	48	"
7-30-85	123	142	50	"
7-31-85	135	154	58	"
8-01-85	135	188	70	
8-02-85	138	230	80	"
8-05-85	162	312	60	"
8-06-85	173	312	65	"
8-09-85	188	500	45	"
8-12-85	22	20	0	"
8-13-85	22	20	18	"
8-14-85	27	25	42	"
8-16-85	50	80	50	"
8-19-85	77	77	80	"
8-20-85	84	91	50	"
8-21-85	93	89	30	"
8-22-85	22	22	0	"
8-23-85	22	20	0	"
8-26-85	47	22	25	"
8-27-85	25	22	8	"
8-28-85	22	22	2	"
8-29-85	22	20	0	"
8-30-85	22	16	B	"
9-03-85	22	16	"	"
9-04-85	20	16	"	"
9-05-85	20	16	"	"
9-06-85	20	16	"	"
9-09-85	20	20	"	"
9-10-85	16	22	"	"
9-11-85	16	16	"	"
9-12-85	16	22	"	"
9-13-85	16	20	"	"
9-16-85	16	20	"	"
9-17-85	16	16	"	"
9-18-85	16	20	"	"
9-19-85	20	20	"	"
9-20-85	16	16	"	"
9-23-85	16	12	"	"
9-24-85	16	12	"	"
9-25-85	16	12	"	"
9-26-85	16	12	"	"
9-27-85	16	12	"	"
9-30-85	20	16	"	"
10-01-85	16	12	"	"
10-02-85	16	12	"	"
10-03-85	16	22	"	"
10-04-85	16	16	"	"
10-07-85	20	16	"	"
10-08-85	16	16	"	"
10-09-85	22	20	"	"
10-15-85	20	20	"	"
10-21-85	20	20	"	"

B = Broken
(1) All units are centibars
(2) Preset, nonadjustable 20-30 cb. sensor.

PLANT NUMBER 7 (1)

DATE\DEPTH	Soil Moisture Blocks 3"	Soil Moisture Blocks 3"	Watermaster 3"	Hydrovisor (2) 4"
10-23-85	20	20	B	20-30
10-25-85	20	20	"	"
10-28-85	22	22	"	"
10-30-85	20	20	"	"
11-01-85	22	22	"	"
11-04-85	22	22	"	"
11-06-85	22	22	"	"
11-08-85	22	22	"	"
11-12-85	27	27	"	"
11-13-85	27	25	"	"
11-15-85	27	27	"	"
11-18-85	27	25	"	"
11-20-85	27	27	"	"
11-22-85	27	27	"	"
11-25-85	25	25	"	"
11-27-85	25	25	"	"
12-02-85	22	25	"	"
12-04-85	22	22	"	"
12-06-85	22	22	"	"
12-09-85	27	27	"	"
12-11-85	29	29	"	"
12-13-85	29	29	"	"
12-16-85	29	29	"	"
12-18-85	29	29	"	"
12-23-85	27	29	"	"
12-26-85	26	29	"	"
12-27-85	29	29	"	"
12-31-85	25	25	"	"
1-02-86	25	25	"	"
1-03-86	25	25	"	"
1-07-86	25	25	"	"
1-09-86	27	27	"	"
1-10-86	27	27	"	"
1-13-86	27	27	"	"
1-16-86	25	25	"	"
1-17-86	22	22	"	"
1-21-86	25	25	"	"
1-23-86	22	22	"	"
1-24-86	25	25	"	"
1-27-86	27	27	"	"
2-04-86	22	22	"	"
2-06-86	27	25	"	"
2-07-86	27	27	"	"
2-10-86	27	27	"	"
2-11-86	27	27	"	"
2-14-86	27	27	"	"
2-24-86	22	20	"	"
2-26-86	20	20	"	"
2-28-86	20	20	"	"
3-03-86	20	20	"	"
3-05-86	20	20	"	"
3-06-86	20	25	"	"
3-12-86	20	20	"	"
3-14-86	22	20	"	"
3-17-86	22	22	"	"
3-20-86	22	20	"	"
3-24-86	20	20	"	"
3-26-86	20	20	"	"
3-28-86	20	16	"	"
3-31-86	20	20	"	"

B = Broken
(1) All units are centibars
(2) Preset, nonadjustable 20-30 cb. sensor.

PLANT NUMBER 7
(1)

DATE\DEPTH	Soil Moisture Blocks 3"	3"	Watermaster 3"	Hydrovisor (2) 4"
4-02-86	22	20	B	20-30
4-04-86	22	20	"	"
4-09-86	20	20	"	"
4-11-86	20	16	"	"
4-14-86	20	16	"	"
4-18-86	20	16	"	"
4-21-86	20	16	"	"
4-24-86	20	20	"	"
4-28-86	20	22	"	"
4-30-86	20	20	"	"
5-01-86	22	20	"	"
5-05-86	20	22	"	"
5-06-86	22	25	"	"
5-09-86	20	22	"	"
5-12-86	20	22	"	"
5-14-86	16	22	"	"
5-19-86	16	22	"	"
5-23-86	20	20	"	"
5-27-86	20	16	"	"
6-02-86	20	16	"	"
6-04-86	20	20	"	"
6-09-86	20	20	"	"
6-11-86	16	16	"	"
6-13-86	20	16	"	"
6-18-86	20	20	"	"
6-20-86	20	16	"	"
6-23-86	16	16	"	"
6-26-86	16	16	"	"
7-01-86	16	16	"	"
7-07-86	20	20	"	"
7-09-86	20	B	"	"

B = Broken
(1) All units are centibars
(2) Preset, nonadjustable 20-30 cb. sensor.

PLANT NUMBER 8 (1)

DATE\DEPTH	Soil Moisture Blocks 3"	Soil Moisture Blocks 3"	Watermark 3"	Watermark 8"	Watermaster 3"
4-04-86	22	20	(2)	28	B
4-09-86	16	16	"	8	"
4-11-86	16	16	"	5	"
4-14-86	16	20	"	31	"
4-18-86	20	16	"	23	"
4-21-86	27	12	"	28	"
4-24-86	52	12	"	39	"
4-28-86	45	12	"	28	"
4-30-86	69	12	"	39	"
5-01-86	68	12	"	44	"
5-05-86	38	12	"	23	"
5-06-86	45	12	"	28	"
5-09-86	91	5	"	45	"
5-12-86	80	9	"	49	"
5-14-86	80	9	"	45	"
5-19-86	131	27	"	57	"
5-23-86	87	25	"	52	"
5-27-86	127	29	"	64	"
6-02-86	162	66	"	127	"
6-04-86	165	68	"	132	"
6-09-86	169	63	"	144	"
6-11-86	181	87	"	75	"
6-13-86	158	61	"	77	"
6-18-86	165	65	"	75	"
6-20-86	173	74	"	83	"
6-23-86	196	98	"	88	"
6-26-86	220	146	"	103	"
7-01-86	185	142	"	121	"
7-07-86	200	177	"	140	"
7-09-86	169	B	"	134	"

B = Broken
(1) All units are centibars.
(2) Sensor connected to electronic module at 35 cb. level.

PLANT NUMBER 8
(1)

DATE\DEPTH	Soil Moisture Blocks 3"	3"	Watermark 3"	8"	Watermaster 3"
10-21-85	27	25	(2)	45	B
10-23-85	25	25	"	39	"
10-25-85	27	27	"	52	"
10-28-85	27	27	"	62	"
10-30-85	25	25	"	52	"
11-01-85	25	25	"	8	"
11-04-85	22	22	"	2	"
11-06-85	25	22	"	28	"
11-08-85	25	22	"	18	"
11-12-85	25	25	"	2	"
11-13-85	25	25	"	8	"
11-15-85	27	25	"	8	"
11-18-85	25	25	"	8	"
11-20-85	27	25	"	8	"
11-22-85	25	25	"	8	"
11-25-85	22	25	"	2	"
11-27-85	22	22	"	2	"
12-02-85	20	20	"	1	"
12-04-85	20	20	"	0	"
12-06-85	20	20	"	1	"
12-09-85	25	22	"	1	"
12-11-85	27	25	"	8	"
12-13-85	27	27	"	13	"
12-16-85	27	25	"	18	"
12-18-85	27	25	"	18	"
12-23-85	25	25	"	28	"
12-26-85	27	25	"	34	"
12-27-85	29	29	"	4	"
12-31-85	22	22	"	2	"
1-02-86	22	22	"	2	"
1-03-86	22	20	"	2	"
1-07-86	22	22	"	2	"
1-09-86	22	22	"	5	"
1-10-86	22	22	"	5	"
1-13-86	25	22	"	11	"
1-16-86	22	22	"	2	"
1-17-86	16	20	"	2	"
1-21-86	20	20	"	8	"
1-23-86	20	20	"	2	"
1-24-86	22	22	"	2	"
1-27-86	25	22	"	8	"
2-04-86	20	20	"	2	"
2-06-86	22	22	"	2	"
2-07-86	22	22	"	8	"
2-10-86	25	22	"	18	"
2-11-86	22	22	"	23	"
2-14-86	22	22	"	20	"
2-24-86	20	20	"	8	"
2-26-86	16	16	"	13	"
2-28-86	16	16	"	18	"
3-03-86	16	16	"	28	"
3-05-86	20	16	"	8	"
3-06-86	16	12	"	22	"
3-12-86	20	16	"	1	"
3-14-86	16	16	"	1	"
3-17-86	22	20	"	2	"
3-20-86	22	16	"	15	"
3-24-86	20	16	"	2	"
3-26-86	20	16	"	13	"
3-28-86	16	9	"	23	"
3-31-86	20	16	"	39	"
4-02-86	22	20	"	2	"

B = Broken
(1) All units are centibars.
(2) Sensor connected to electronic module at 35 cb. level.

PLANT NUMBER 8
(1)

	Soil Moisture Blocks		Watermark		Watermaster
DATE\DEPTH	3"	3"	3"	8"	3"
4-04-86	22	20	(2)	28	B
4-09-86	16	16	"	8	"
4-11-86	16	16	"	5	"
4-14-86	16	20	"	31	"
4-18-86	20	16	"	23	"
4-21-86	27	12	"	28	"
4-24-86	52	12	"	39	"
4-28-86	45	12	"	28	"
4-30-86	69	12	"	39	"
5-01-86	68	12	"	44	"
5-05-86	38	12	"	23	"
5-06-86	45	12	"	28	"
5-09-86	91	5	"	45	"
5-12-86	80	9	"	49	"
5-14-86	80	9	"	45	"
5-19-86	131	27	"	57	"
5-23-86	87	25	"	52	"
5-27-86	127	29	"	64	"
6-02-86	162	66	"	127	"
6-04-86	165	68	"	132	"
6-09-86	169	63	"	144	"
6-11-86	181	87	"	75	"
6-13-86	158	61	"	77	"
6-18-86	165	65	"	75	"
6-20-86	173	74	"	83	"
6-23-86	196	98	"	88	"
6-26-86	220	146	"	103	"
7-01-86	185	142	"	121	"
7-07-86	200	177	"	140	"
7-09-86	169	B	"	134	"

B = Broken
(1) All units are centibars.
(2) Sensor connected to electronic module at 35 cb. level.